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INTEGRAL BRIDGE CONCEPT APPLIED TO REHABILITATE AN EXISTING BRIDGE AND CONSTRUCT A DUAL-USE BRIDGE

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Abstract

In this article two case studies are presented where the integral bridge concept has been advantageously adapted: strengthening of an existing bridge & construction of a new dual-use bridge. During the investigations, assessment & upgrading of an existing prestressed concrete bridge over a tidal river, a number of proposals for strengthening the bridge to carry heavier vehicular loads were studied. Conversion of the existing simply supported deck to be integral with abutments was found to suit the site conditions. Effectiveness of strengthening were confirmed by monitoring system using strain gages & accelerometers. In the second case integral bridge concept was successfully implemented in a D & B contract. This dual use bridge across a canal carries six circuits of 400kV lines at soffit level and would be carrying road traffic in the transverse direction in the future. The integral bridge using two precast post-tensioned girders connected by cast in-situ diaphragms and deck slab presented many interesting features.

Keywords: integral bridge, strengthening, prestressed concrete, bridge-monitoring system

1. Introduction

Integral bridges also called, as integral abutment bridges are jointless bridges where the deck is continuous and connected monolithically with the abutment wall with a moment-resisting connection founded generally on a single row of piles. Integral bridges eliminate the problems associated with movement joints and bearings and provide the following advantages:

- Increase redundancy, enhance load distribution at support & provide better overall structural system particularly under seismic loading
- Provide superior protection for girder ends
- Reduce maintenance costs and increase service life

The design of integral bridges is complicated by the non-linear soil-structure interaction of laterally loaded piles. The level of compaction in the granular fill behind the abutment wall and adjacent to the piles strongly dominate the overall soil reaction and the overall structural response of the system.

2. Analysis and design

Depending on the relative flexural stiffness of the bridge deck, abutment wall, foundation piles and lateral stiffness of the soil behind the wall and next to the piles, the amount and mode of deformation of the wall under thermal, gravity and seismic loading varies affecting the level and amount of the soil reaction pressure behind the wall between the limits of active and passive states. In general, the soil springs are non-linear, with some ultimate resistance dependent upon confining stress level, soil type, level of soil compaction, soil strength and mode of wall deformation. Two options are available for analysis:

2.1 Iterative equivalent linear approach

The lateral soil stiffness behind the wall and translational and rotational stiffness of the soil-pile system are first estimated based on the estimated magnitude of the lateral loads or displacements to be transferred from the deck to the soil system. The soil-pile system is modelled as an equivalent length of horizontally unsupported cantilever beam-column [6][7][8][9] valid at the assumed loading and displacement level. An average value of lateral earth pressure coefficient, K is used to estimate the magnitude and location of the resultant soil force acting behind the abutment wall. The equivalent structural system is then analysed for different loading cases using 2D or 3D finite element analyses. The computed displacement levels are compared with the assumed values and the lateral soil pressure distribution, average value of K and equivalent length of piles are adjusted as necessary and the analyses redone until the assumed and calculated deflections match within the required tolerance.

2.2 FEM analysis using non-linear spring supports

Design curves for estimating the non-linear force-deflection response of soil behind rigid abutment wall in active and passive regimes are available in the design manuals such as NCHRP [1], US Department of Navy [2], Canadian Geotechnical Society [3], Clough and Duncan [5]. For the analysis of lateral loading of vertical piles, the piles are modelled as an elastic beam column and the soil as a series of uncoupled 'Winkler' springs with non-linear p-y curves and hyperbolic T-Z (Q-Z) curves based on the API [4] design guidelines for fixed offshore platforms. At a given depth z, the p-y design curve recommended by API is a continuous hyperbolic tangent curve

$$p = A \cdot p_u \cdot \tanh [k_1 \cdot z \cdot y / A / p_u]$$

where p_u = estimated ultimate resistance calculated based on approximate failure analysis with units of force/length; k_1 = soil stiffness (units of force/length^3); and A = empirical factor accounting for cyclic or static loading, all three terms vary with depth. Pile response is obtained by an iterative solution of a fourth-order differential equation using finite differences techniques in computer programs such as LPILE [8] and COM624P [9]. The solutions recognize that as the backfill is acted upon for several cycles, it becomes remoulded.

Non-linear spring supports available in commercial FEM packages such as GTSTRUDL, SAP2000NL, STAAD.Pro, etc are used to carry out the analysis. Results from the study [10] carried out for the 45m long 3-span composite deck bridge over the Nashua River in Fichburg, Mass. and companion research [11] conducted at the University of Massachusetts have been used to refine the design procedure for integral abutment bridges in [12]. Procedure for adoption of steel H-piles in integral abutment bridges is covered in references [13] and [14].

3. Case studies

Concept of integral bridge could be advantageously used in many situations: strengthening of existing bridges, construction of new bridges with skew alignments, etc. Two case studies are presented here below to illustrate the versatility of the system.

3.1 Strengthening of an existing prestressed concrete bridge

The first case involves investigations, assessment & upgrading of an existing prestressed concrete bridge (Figures 1 & 2) over a tidal river. It was designed and built in 1968-70 to carry MOT 'Standard Highway Loadings' Memo No. 771, HMSO, 1961. It is of span length 18.16m c/c of bearings carrying 4-lane undivided carriageway with 1.5m wide footpaths on either side. The superstructure is made of precast pretensioned inverted T-beams connected by cast in-situ reinforced concrete diaphragms & deck slab. Elastomeric bearings have been used to transfer the loads from the deck to the substructure consisting of reinforced concrete cantilever wall type abutments & return walls resting on precast reinforced concrete square piles. The enhanced vehicular loading of the client demanded strengthening of the main girders for flexure by one of the following options:

- Externally bonded steel plate or composite material
- External prestressing
- Conversion of the simply supported system to integral bridge

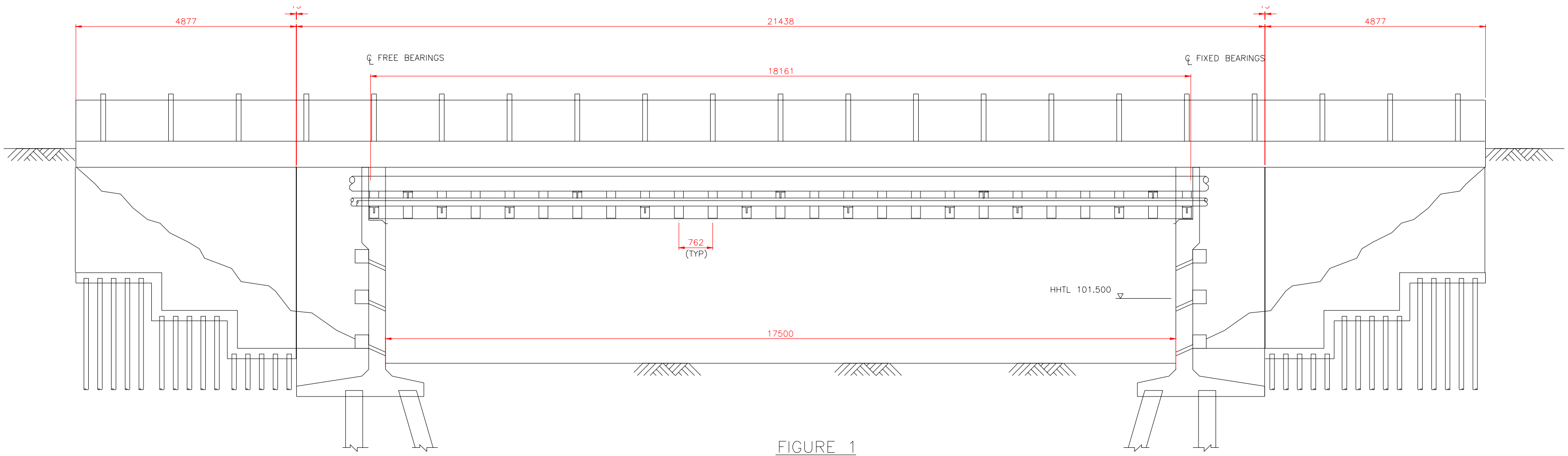


FIGURE 1

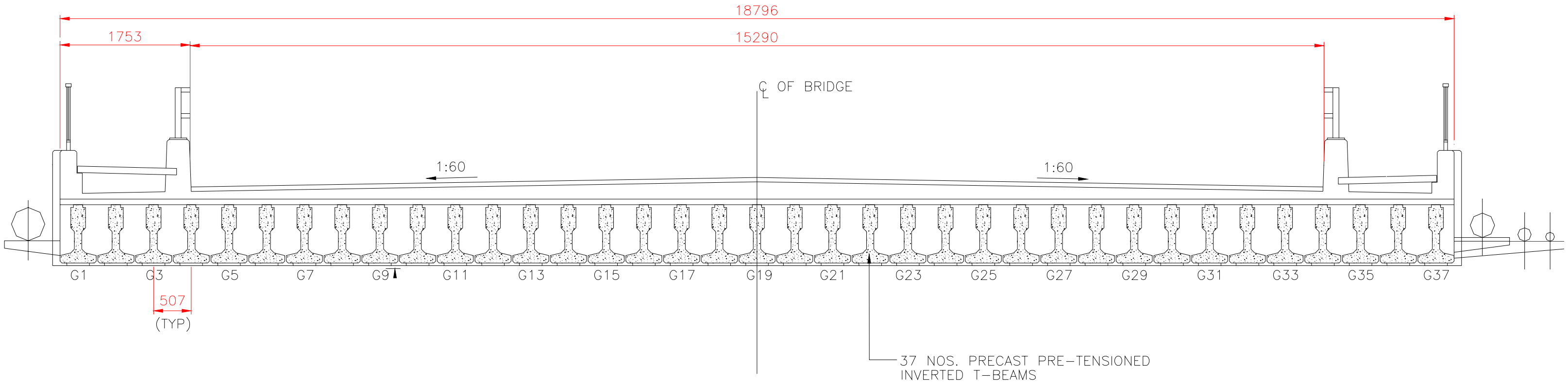
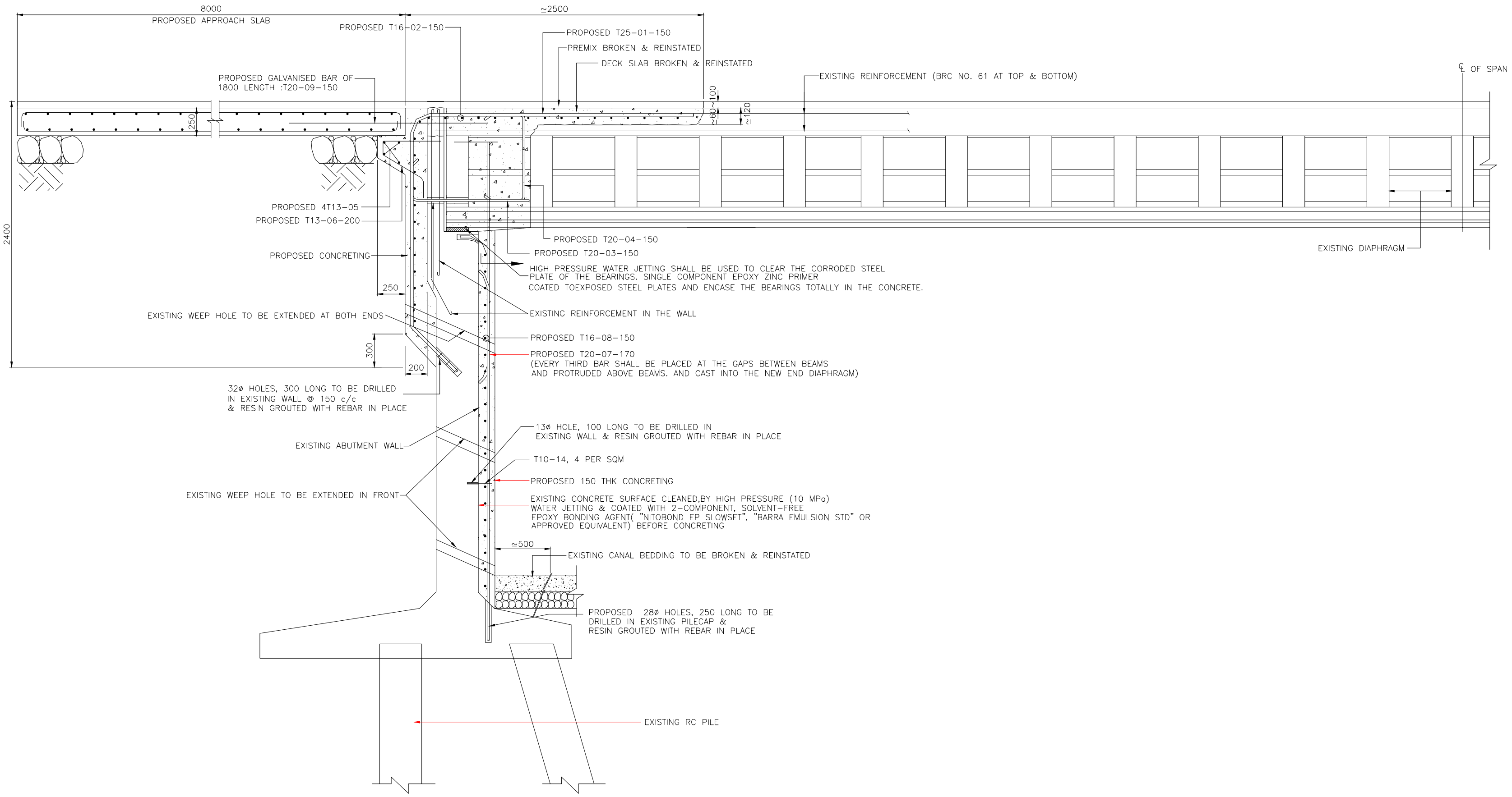


FIGURE 2



HIGH PRESSURE WATER JETTING SHALL BE USED TO CLEAR THE CORRODED STEEL PLATE OF THE BEARINGS. SINGLE COMPONENT EPOXY ZINC PRIMER COATED TOEXPOSED STEEL PLATES AND ENCASE THE BEARINGS TOTALLY IN THE CONCRETE.

(EVERY THIRD BAR SHALL BE PLACED AT THE GAPS BETWEEN BEAMS AND PROTRUDED ABOVE BEAMS. AND CAST INTO THE NEW END DIAPHRAGM)

EXISTING CONCRETE SURFACE CLEANED,BY HIGH PRESSURE (10 MPa) WATER JETTING & COATED WITH 2-COMPONENT, SOLVENT-FREE EPOXY BONDING AGENT("NITOBOND EP SLOWSET", "BARRA EMULSION STD" OR APPROVED EQUIVALENT) BEFORE CONCRETING

FIGURE 3

Conversion of the existing simply supported deck to be integral with the abutments was found to suit the site conditions where heavy vehicular & container traffic have to be maintained during the upgrading works. The following procedure (Figure 3) was adopted for the conversion to integral abutment bridge:

- Break the wearing surfaces near abutment and concrete of top slab corner and excavate behind abutment to enable addition of flexural reinforcement at top
- Clean with high pressure water jet the exposed steel plates of elastomeric bearings and apply protective coating before encasing them with concrete at diaphragm and form nib for approach slab
- Divert stream flow and break canal bedding to enable addition of reinforcement on the front face of abutment wall and concreting and reinstate canal bedding and divert back stream flow
- Backfill and compaction, concrete approach slab and reinstate wearing course.

Structural model used for the analysis and design of the moment resisting connection is shown in Figure 4. Effectiveness of the strengthening works was checked by the bridge health monitoring system described in section 4.

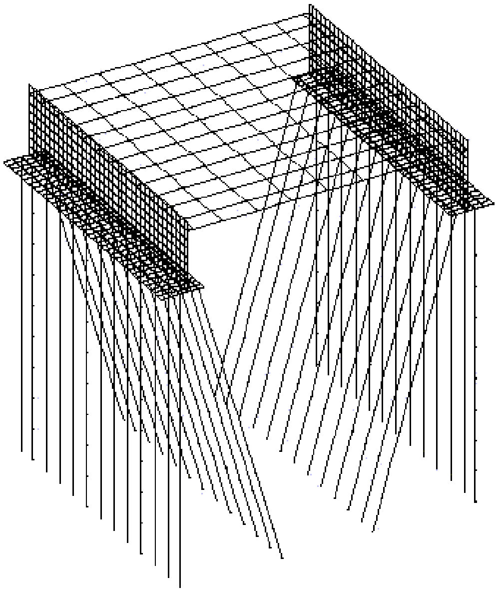


Figure 4

3.2 Construction of a dual-use bridge

Integral bridge concept was successfully implemented in a design and build contract. This dual use bridge across a canal carries six circuits of 400kV lines at soffit level and would be carrying road traffic in the transverse direction in the future when the proposed highway running over and along the canal materialises. The 41.5m span integral bridge (Figures 5 & 6) consists of two precast prestressed concrete box girders connected by cast in-situ slab at deck level and diaphragm / abutment cum pile-cap at the ends Precast reinforced concrete double T-beams have been used at the soffit level with reinforced concrete walls to separate the central four circuits. This bridge presents the following features:

- Intermediate foundations in the canal (proposed in the original departmental design) avoided;
- Contiguous bored piles adopted for the abutment/support diaphragm acting as cut-off wall to enable transitions to be constructed to the canal in the future;
- Cross-section of superstructure elements and stages of prestressing adopted to satisfy the vertical clearance above the HFL and the top level of the bridge to match the top level of the adjacent bridge besides accommodating the cranage limitation of the contractor.

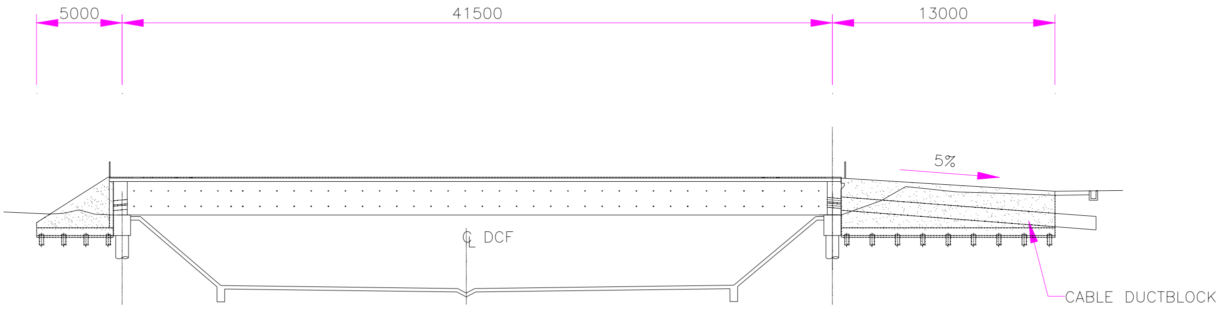


FIGURE 5

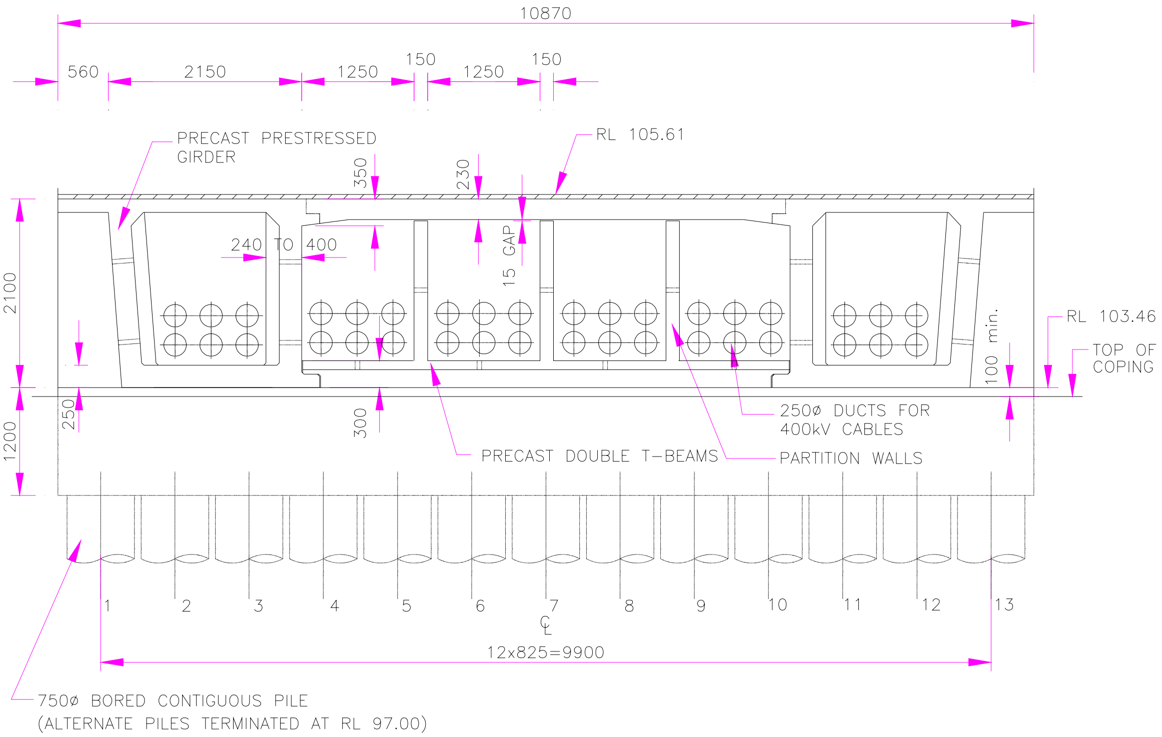


FIGURE 6

Structural model used for the analysis and design is shown in Figure 7.

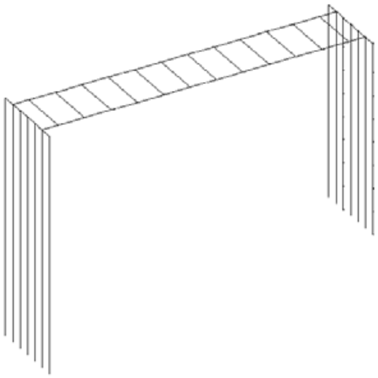


Figure 7

4. Bridge health monitoring system

The evaluation of the in-field performance of bridges is dependent on many assumptions associated with the analytical model (boundary conditions, influence of kerbs, membrane action, etc), loading model and the resistance model (material properties, condition, etc). Bridge health monitoring data acquisition system measure the response of a bridge to its actual traffic load and compares the response with the expected response. Monitoring the traffic effects for a short period of time and extrapolating this data using statistical and probability methods provides an economic and viable alternative for assessing a bridge. For an effective monitoring system to be designed, an initial structural measurement and analysis is carried out to obtain a baseline performance against which the performance after upgrading will be compared. From the initial modal analysis, the optimum locations for the mounting of the monitoring system sensors are decided. After the upgrading, the structural measurement and analysis is repeated to verify the structural improvements achieved.

For the bridge referred to in 3.1, vibration testing (ambient as well as forced vibration) was carried out adopting a procedure similar to the one used by EMPA (Switzerland) to test one of their highway bridges[15]. Four demountable stain gages were fixed to the soffit of the bridge deck at the midspan & three accelerometers were placed at midspan & quarter spans and HMX Bridge Health Monitor was used to record data from the sensors. The maximum deflection of the deck under live load is estimated to be reduced from 17.6mm to 13.2mm on conversion to integral abutment bridge. Following are the measurements obtained for the first mode of vibration of the bridge:

Before strengthening:	5.0 Hz
After strengthening:	8.8 Hz

This establishes the effectiveness of the conversion to integral bridge in flexural strengthening of the deck.

5. Conclusion

Concept of integral abutment bridge could be advantageously used in various situations. With increasing confidence in the non-linear finite element analysis for integral abutment bridges, effect of backfilling with loose granular fill, adoption of H-piles in pre-augered holes, etc. could be investigated and adopted if found suitable.

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