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Parametric and pushover analyses on integral abutment bridge

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ABSTRACT

Integral abutment bridges (IABs) are jointless bridges where the girder or the deck is continuous and monolithically connected to the abutments. A usual and important problem in the design of IABs is how to deal with the soil–structure interaction behind the abutments and next to the foundation piles: this can be considered as a fundamental aspect to reach a thorough understanding of this type of structure, which requires iterative and nonlinear analysis. In this paper, a 2D simplified finite-element model of a real 400-metre-long IAB, built in the Province of Verona-Italy, is implemented and used to perform non-linear analyses on the bridge, the structural response of which is then examined in detail. A parametric study based on the variation of the soil properties behind the back-walls and around the piles is then performed. Furthermore, a temperature pushover analysis (non linear static analysis for positive and negative temperature variations) is carried out to assess the failure pattern of the bridge caused by a temperature change, considered as one of the key parameters in IAB design. Lastly, the effect of abutment stiffness is also discussed.

1. Introduction

In recent years the integral abutment bridge (IAB) concept has become quite common. It is, incidentally, not a newly developed concept as its formulation dates back at least to the 1930s and was introduced to deal with long-term structural problems frequently occurring with conventional bridge design. The original IAB concept was not well managed at that time and it turned out to cause numerous problems relating to the post-construction life of the structure due to the specific type of design and to the soil–structure interaction problems that still represent a challenging issue that requires a close cooperation between structural and geotechnical engineers. The IAB concept is currently generating much interest among bridge engineers because of the enormous benefits deriving from the elimination of expansion joints and the reduced installation and maintenance costs accruing. The superstructure of integral abutment bridges is made continuous through a composite cast-in-place concrete slab over prestressed concrete or steel girders and rigid transverse diaphragms: the system, made up of the sub- and the super-structure, acts as a single structural unit [1,2].

The connection between the super-structure and the sub-structure makes IABs different from other conventional bridges and allows for a remarkably increased redundancy, with improved response during seismic and other extreme events. Furthermore, the IAB concept has proved to be successful in eliminating a number of problems related to the management of conventional bridges during their service life, thus resulting as a more financially viable solution in terms of both construction and maintenance costs [2]. It would be rather naïve, though, to consider this kind of structure as "maintenance-free" as the IAB concept indeed suffers from an intrinsic and fundamental flaw deriving from the need to accommodate the different displacements between superstructure and soil, mainly by seasonal fluctuations of air temperatures. Also, as is usual for statically undetermined structures, the effects of temperature changes have to be carefully evaluated. The large number of uncertainties involved in the analysis — such as on-site real temperature conditions and soil mechanical characteristics — for IABs, parametric analyses is particularly useful in assessing the expected structural response.

2. Engineering background—the *Isola della Scala* bridge

The case study presented concerns a flyover (Fig. 1), completed in 2007 and located at *Isola della Scala* in Verona, Italy. The total length of the structure, arranged on 13 spans, is approximately 400 m. To the authors' knowledge, this is currently the longest IAB ever built. The construction of the bridge, which began in 2001 as a simple supported flyover, was halted after 2 years because of

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Fig. 1. Photo of *Isola della Scala* bridge during construction.

Table 1
Main features of the *Isola della Scala* bridge.

Total length		400 m
Number of the spans		13
Single span length		30 m
Static scheme: Pre-refurbishment		Simply supported
Post-refurbishment		Continuous
Number of beams per bay in the cross section		6
Deck width		13.5 m
Beams height		150 + 30 cm
Piers column diameter		3.0 m
Piers height (cap + column + footing):	P1	180 cm + 377.5 cm + 250 cm
	P2	180 cm + 430.0 cm + 250 cm
	P3	180 cm + 461.9 cm + 250 cm
	P4	180 cm + 473.5 cm + 250 cm
	P5	180 cm + 473.5 cm + 250 cm
	P6	180 cm + 538.5 cm + 250 cm

Table 2
Pile properties of the *Isola della Scala* bridge.

	Beneath abutments	Beneath pier footings
Material	Concrete C35/40	
Reinforcement	30φ26 mm with cover of 40 mm	
Type	Friction	
Numbers	4+ 2	3 × 2
Section shape	Circular	
Diameter (m)	1.20	
Length (m)	15	20

economic problems affecting to contractor. At that time, all pre-stressed concrete girders and the main pre-fabricated elements were nevertheless purchased. In early 2006, works resumed with a new proposal that aimed to improve the quality of the structure and change the static scheme from "simply supported" to "fully integral". This goal should not involve modifying those parts of the bridge which had already been built [3] such as the abutments and the piers. Moreover, the new design phase should avoid an increase in the overall cost of the structure. The main features of the bridge are given in Tables 1 and 2. The elevation layout is shown in Fig. 2. Details of the typical cross section are given in Fig. 3. The piles arrangements are shown in Fig. 4. During this kind of "refurbishment" process, in order to achieve an IAB, eliminating all bearings and expansion joints, resistance to bending moment was attained at the pier caps with the casting of concrete diaphragms between the beams of adjacent spans at the pier tops. Hogging and sagging moment resistance was also determined with a similar technique at the abutments for the end bays. The connections between the beams of adjacent spans were carried out by casting the concrete of the diaphragms also inside the V-shaped girders for a length of 2 m (Fig. 5) [2,3]. The connections between the pier-caps and the transverse diaphragm were achieved with a segment of steel beam for every beam (Fig. 5). During construction, average air temperature remained approximately 10–15 °C. The construction sequence of the transverse diaphragms started from the central part of the bridge (piers 6 and 7) and proceeded symmetrically towards the abutments.

The bridge was opened to traffic in 2007 and no mentionable damages have been noticed until now, except for some uniformly distributed cracks in the approach slabs.

3. Description of the analysis model

3.1. Geotechnique

A geotechnical investigation aiming to assess the local soil layers together with related mechanical properties was performed on-site. Soil penetration tests were carried out. Due to the uncertainties deriving from the extension of the construction site, initial experimental data were completed with data and analyses found in literature. Integral abutment bridges are significant examples for highlighting the importance of a thorough investigation of the soil–structure interaction. The soil reaction pressure distribution, which is a major factor of interest for the abutment walls and the foundation piles, is inherently non-linear and varies with depth, amount and mode of wall displacement [4–7].

3.1.1. Soil–abutment interaction

Non-linear springs were used to model the soil–abutment interaction (Fig. 6). The backfill behind the abutment walls and under the approach slabs is made up of a compacted cohesionless granular filling. On the basis of the comparison between different design curves found in literature and describing soil–abutment interaction, the NCHRP design curves were used in this study [8,9] (Fig. 7).

The general form of the NCHRP lateral earth pressure coefficient K versus deflection design curves was implemented for loose, medium-dense and dense soils. These curves relate the horizontal