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*This issue of Structural Engineering International (SEI) will present articles with the topic **Integral Bridges, Fibre Reinforced Polymer Composites** and **General Structural Engineering Reports** on worldwide structures and papers on recent cutting-edge research and technology. The tentative list is expected to include the following papers.*

Scientific Reports

Fatigue Retrofitting of Welded Steel Cover Plates Using Pre-Stressed CFRP Strips

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Past research on the use of carbon fibre reinforced polymer (CFRP) strips for the fatigue retrofitting of steel structures has shown that these materials have considerable potential for this application. Several investigations have found that this approach can be significantly improved by first pre-stressing the strips. To further explore this possibility, a study was recently undertaken with the objectives of: 1) fatigue testing steel beams with welded cover plates strengthened using pre-stressed CFRP strips, and 2) employing analytical models to predict the resulting fatigue life increase. This paper summarizes the main findings of this study. Specifically, it is shown that a significant fatigue life increase can be achieved with the application of pre-stressed CFRP strips to welded details, such as cover plates. This increase will be modest, however, if the introduced stress is less than the residual stress already present due to the welding process. The test results are predicted by a fracture mechanics model, wherein the stresses in the weld are determined by finite element analysis.

Keywords: *steel welds, fatigue, retrofitting, carbon fibre, fracture mechanics.*

Performance-Based Seismic Retrofit of Existing Reinforced Concrete Frame Buildings using FRP: Challenges and Solutions

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The need for simple and cost-effective seismic retrofit solutions for existing reinforced concrete buildings, particularly those designed before the 1970s, thus prior to the introduction of modern seismic code provisions and capacity design principles has been eventually recognized as a critical socio-political priority at international level. Similarly to what pursued for the design of new structures, a performance-based approach should be adopted when assessing the vulnerability and defining the retrofit strategy for existing buildings. In this contribution, an overview of recent evidence-based developments in the field of FRP strengthening of existing reinforced concrete (R.C.) frame systems have been presented. Based on experimental tests, and analytical-numerical results as well as experience from onsite applications, particular focus has been given to the discussion on feasibility and efficiency of low-invasive implementation techniques targeting the exterior corner joints of a building in order to guarantee minimum interruption to the functionality of the building.

Keywords: *performance-based design; fiber reinforced polymers; rehabilitation; seismic effects; beam-column joints; biaxial tests; masonry infill.*

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Case Studies on Advanced Composite Materials for Civil Engineering and Architectural Applications

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Due to their light weight, high stiffness-to-weight and strength-to-weight ratios, and high resistance to environmental degradation, resulting in lower life-cycle costs, advanced composites materials, commonly known with the acronym FRP, are increasingly being considered for use in civil engineering applications, ranging from the retrofit and rehabilitation of buildings and bridges to the restoration and strengthening of historical-monumental masonry structures. Thanks to the recently published Italian FRP guidelines, CNR-DT 200/2004, by the Italian National Research Council, there has been an increasing demand for their implementation for general strengthening and retrofitting applications as well as for seismic mitigation of structures and infrastructures, and the recent earthquake of L'Aquila has decreed their use as the most efficient technological solution for strengthening, repairing and seismic upgrade of most structural elements in existing buildings, showing also, for the first time, the official implementation of UHTSS steel fiber sheets. In this paper, several case studies have been reported demonstrating the different field of applications of the different fibers and technological solutions.

Keywords: *FRP, SRP, SRG, UHTSS steel fibers, biocomposites, flax fibers, hemp fibers, basalt fibers, strengthening, retrofitting, seismic upgrade.*

Integral Bridge for High-Speed Railway

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It could be said that for many centuries mankind built only integral bridges, though the current concept is less than a century old. The essential characteristic of an integral bridge is the absence of structural discontinuities, such as expansion joints and sliding supports. As a consequence the expansions and contractions of the deck affect the abutments and piers; such effects are minimised in a conventional bridge. On the other hand an integral design offers the advantages associated with structural monolithism: all piers and abutments can collaborate towards a distributed transmission of the horizontal loads to the ground; also, the redundancy of the structure produces a more desirable global response and contributes ductility to the potential failure modes. The ability to transmit large horizontal forces to the ground in an orderly fashion is particularly significant in railway bridges, which must be designed to withstand considerable loads from the emergency braking of trains, as well as those arising from seismic action. Apart from those advantages, the absence of joints and bearings makes construction easier and faster, and also results in maintenance savings. Jointless highway bridges are relatively common in many parts world, with the United States accounting for at least 13 000 of them. In the United Kingdom bridge decks up to 60 m in length with skews below 30º are generally required to be continuous over intermediate supports and integral with their abutments. However, in spite of this wealth of experience, the design rules vary widely. Researchers have reported recently the results of a survey sent to all the transportation agencies in the US and Canada, which was answered by 34 in the US and one in Canada: jointless bridges made of prestressed concrete have their dimensions limited to lengths ranging from 45,7 m to 358 m, their skew angles from 15 degrees to 70 degrees, and their curvatures from 0 degrees to no limit. The inevitable conclusion from such variety of criteria in a relatively close geographical environment is that there is only limited common understanding as to how integral bridges perform and what are the mechanisms that may eventually fail them. In Spain, the length of integral highway bridges is not specifically limited, but the horizontal displacements of the deck cannot exceed 30 mm, which in practice limits the length to about 100 m, even before accounting for shrinkage and creep. And there are also other limitations, like 60 degrees on skew and a radius of curvature that must exceed 10 times the deck width. In spite of the relative scarcity of national criteria, and the at times conflicting character of the existing ones, it is a fact that in recent years integral bridges have been generally becoming increasingly popular in Europe.

Keywords: *Integral bridges, railway bridges, vibration.*

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Analytical Formulation for Limit Length of Integral Abutment Bridges

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The Integral Abutment bridge concept has recently become a topic of remarkable interest among bridge engineers not only for newly built bridges but also during refurbishment processes. In fact, the superstructure of integral abutment bridges can be made continuous through a composite cast-in-place concrete deck slab over pre-stressed concrete or steel girders. The system constituted by the sub-structure and the super-structure can achieve a composite action responding as a single structural unit; this principle is clearly applicable also to convert existing simply supported bridges into IABs. Several guidelines for the design of IABs have been published in the last few years. The main idea is to lead the designers into this kind of structures limiting their total length, the skewness and the inclination of the deck. The maximum lengths usually recommended for this kind of structures are around 100 meters or even less. This limitation derives from the difficulties introduced by the need of controlling the soil-structure interaction for the imposed temperature variations: this is in fact the main factor affecting the possibility of increasing the overall length of the structure. A very interesting issue is the search for the maximum length attainable with this kind of structures, which is intrinsically related to the thorough understanding of the soil-structure interaction behind the abutments or next to the foundation piles. It is proved that maximum length for IABs can exceed 400 meters. The case of the world record for IABs, which derives from the transformation of a simply supported flyover in Verona-Italy, will be mentioned in the paper together with the non linear parametric analyses carried out to determine the solution presented. The paper will deal with the possibility of achieving super-long IABs using standard pre-fabricated cross sections and typical reinforcement ratios for foundation elements and superstructure.

Keywords: **integral abutment bridge, ultimate length, temperature load, soil-structure interaction.**

Behavior of an Integral Abutment Bridge

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The behaviour of an integral abutment (IA) bridge near Rochester, Minnesota, was investigated from the beginning of construction through approximately 7 years of service using data collected from more than 150 instruments installed in the bridge during construction. Long-term bridge shortening was observed to increase with time, based on the readings of horizontal extensometers installed behind the abutments and strains measured using concrete embedment gauges in the girders. Abutment rotations and measured pile curvatures also steadily increased with time. The time-dependent behaviour of the bridge can be explained from a combination of factors including the concrete creep and shrinkage, the increase of backfill soil pressure, the yielding of the reinforcement across the joint between diaphragm and pile cap, and the alternation of the relative humidity and temperature. In comparing the measured pile axial force and moment data to axial force–moment interaction capacity curves, it was estimated that approximately 20% of the pile flange cross section yielded in compression under the abutment. The likelihood of low-cycle fatigue was determined to be small. On the basis of the findings of this research, it is recommended that the time-dependent effects of concrete IA bridges should be considered in structural design and analysis for both long-term bridge shortening and abutment rotation if these long-term effects are anticipated to be significant. More research is needed to determine the parameters for the cases when a time-dependent analysis of an entire integral bridge system is warranted, that is, bridge length limit and soil condition.

Keywords: *integral abutment; soil–structure interaction; creep; fatigue; thermal gradient.*

A Methodology for Treating Non-Symmetric Loading on Integral Abutment Bridges

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Integral abutment bridges (IAB) are an economic way to design appealing single span bridges. However, experience is missing, as the main difference in the design of IAB compared to conventional bridges is the restraint of the frame corner, caused by the fact that the superstructure and the abutments are one monolithic structure. This leads to modification in design regarding the internal forces and deformations as well as the detailing of the frame corner itself. IAB are generally designed as frames using grid models with idealized superstructure. This calculation involves sophisticated models and is considered to be time consuming. Also conventional single-span bridges are designed with the help of grid models. However for the latter ones, experience and various design software tools exist, especially if simply supported structures are considered. Main problem in the transfer of frame systems into simply supported structures are the interactions between superstructure and substructure. By separating the superstructure from the substructure, the implementation of IAB design into existing software tools is possible. However, to take into account the superstructure-abutment interaction, the superstructure needs to be restrained by rotational springs. Due to sway effects in the original frame, the boundary conditions (horizontal position of the frame corner) for the determination of the rotational spring stiffness variety. Therefore these springs have to be non-linear and thus, do not comply with the demand for load case superposition. This paper presents a new approach to separate the superstructure from the substructure with respecting possible superposition of the load cases. The approach is based on the division of the nonlinear springs into two linear springs, one for symmetric loading, the other one for antimetric loading, from which a modification factor kmgk has been derived. This factor is adjusting the single span model with a single rotational linear spring to the original grid model system. Based on this approach and the kmgk factor, the use of conventional design tools for integral abutment bridges has been made possible. To further close the gap in experience on IAB, design and detailing recommendations are given.

Keywords: *integral abutment bridges, static calculation, antimetric loading, internal forces, detailing.*

Portal Frame Bridges in Japan - State of the Art Report

Akimitsu Kurita, Prof., Dr., Dept. of Civil Engineering and Urban Design, Faculty of Engineering, Osaka Institute of Technology, Osaka, Japan.

In Japan, the portal frame bridge (PFB) has been exclusively used in lieu of the integral abutment bridge (IAB) from about 1995. In the design of the PFB, the structural detailing of the girder–abutment connection becomes very important. Up to now, some structural details for girder–abutment connections have been proposed for bridges constructed in Japan.

A brief history and a few completed PFBs are reported in this paper. The focus lies on PFB with steel composite girders in roadways. Some typical structural details of the girder–abutment connection and few constructed examples are introduced and discussed. A new type of approach slab, which has shear projections on its upper surface, has been developed in Japan and there are already some applied examples. A finite element analysis of the interaction among soil, asphalt pavement and approach slab was conducted and the results are reported and discussed in comparison with the ordinary design.

Keywords: *portal frame bridge; roadway bridge; steel composite girder; approach slab with shear projection; constructed example; prospect of integral abutment bridge.*

Integral Railway Bridges in Germany

Steffen Marx, Prof. Dr.-Ing., Jacobs School of Engineering, University of California, San Diego, USA and Günter Seidl, Dr, Eng., SSF Ingenieure, Berlin, Germany

In Germany, integral bridges for railway lines take a higher level of relevance. This paper describes the recent development of structures with integral abutments and gives an outlook on large bridges currently in the making on newly built railway lines. In the German railway network, reinforced concrete frames for spans up to 20 m have been used for more than 25 years. Lateral launching of frame bridges into existing railway links were an economical option. Following the good experience with frame construction, even longer frame bridges with integral abutments were implemented as an economical variant. The advantages are highlighted by the examples of viaduct Rednitztal, the flying junction Dresdner Bahn and the composite bridge over River Saaleflut. On the

basis of these successful experiences, especially regarding low-cost construction, robust construction type and simple maintenance, these bridges are also integrated into newly built railway lines. The starting point for the construction of frame bridges was the very high-quality design of the frames compared with the single-span girder bridges implemented until then. The bridges on the railway line from Erfurt to Halle/Leipzig, which are currently in progress, are good examples for this implementation. The viaducts Scherkonde, Unstruttal, Gänsebachtal and Stöbnitztal portray in detail the design and construction principles for long frame bridges. In conclusion, the advantages of frame bridges, such as high stiffness, favourable transmission of horizontal loads and simple construction without bearings, are discussed comprehensively and quality is assessed on the basis of the gathered experience.

Keywords: *integral bridges, railway bridges, thermal effects, composites, sustainability.*

Potential of Longitudinal Post-tensioning for Short to Medium Span Timber Bridges
Simona Giorgini, University of Canterbury - Civil and Natural Resources Engineering, Christchurch, New Zealand; Alessandro Palermo, University of Canterbury - Civil and Natural Resources Engineering, Christchurch, New Zealand; Stefano Pampanin, University of Canterbury - Civil and Natural Resources Engineering, Christchurch, New Zealand; Andrew H. Buchanan, University of Canterbury - Civil and Natural Resources Engineering, Christchurch, New Zealand

Based on recent developments in post-tensioned multi-storey timber buildings using unbonded tendons, this paper aims to investigate the potential of implementing similar technology for innovative solutions for timber bridges. In particular, several technological solutions are proposed for future development, using several different cross sections and longitudinal profiles suitable for short to medium bridge spans, with both internal and external longitudinal tendons, in some cases supplemented by transverse post-tensioning. In addition, a feasibility study of a short span timber bridge is presented, with longitudinally post-tensioned LVL hollow core beams as an alternative to the existing concrete solution. The discussion includes a comparison between newly proposed and traditional solution based on the evaluation of long-term post-tensioning losses, a cost analysis and some considerations on sustainability issues.

Keywords: *timber bridges, longitudinal post-tensioning, LVL construction, sustainable construction, feasibility study.*

Technical Reports

A Spanish Perspective on Integral High-Speed Railway Viaducts
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The use of integral viaducts, devoid of support devices and expansion joints in the rails, improves functionality and safety in comparison with traditional railway viaducts, while significantly reducing maintenance costs. However, regulatory requirements often hinder their implementation while fostering oversized conventional alternatives. High-speed railways are the transportation mode of the 21st century and the viaducts that support the track should be yet another manifestation of structural and technological progress. The paper presents some thoughts based on the Spanish experience in this type of structures.

Keywords: *integral viaducts, ductile piers, track tolerances, track-structure interaction, imposed deformations, design actions.*

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Train Buffeting Measurements on an FRP Composite Footbridge

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This paper presents a case study of the Bradkirk Bridge, which is a footbridge installed over a railway line. The bridge, consisting of two 12m spans plus staircases, was manufactured using glass/epoxy FRP material and it is believed to be one of the first moulded FRP bridges to be installed over a mainline network. Due to the lightweight nature of FRP materials, train buffeting of footbridges is an area of considerable interest for designers of FRP structures. The authors have carried out a study comparing onsite measured vibration data with Finite Element Analysis (FEA) and analytical methods to investigate the effect of buffeting on the Bradkirk Bridge. The aim of the study was also in general to understand the dynamic response of the structure and to obtain the natural frequencies. It was found that at the low train speeds measured (less than 70mph), there was no adverse effect on the structure and the structure was found to have a high fundamental natural frequency. There was also a good correlation between the data measured on the bridge and the FEA and theoretical predictions of natural frequencies.

Keywords: *bridges, composites, dynamic effects/vibrations, instrumentation/monitoring.*

A Bridge in China Externally Prestressed by CFRP Tendons

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The Hewei Bridge in Huai'an, Jiangsu Province was the first example of a traffic bridge in China using the CFRP tendons instead of steel tendons. The bridge is an overpass crossing the Nanjing-Xuzhou Expressway, Jiangsu, China. The four middle spans of this bridge are a continuous concrete box girder and pre-stressed by internal steel strands, while both side spans are designed to be the simply-supported monolithic concrete girders of 20 m in length pre-stressed by the external tendons. One span pre-stressed by external CFRP cables, and the other by external ordinary steel tendons for the purpose of comparison. The Hewei Bridge was completed in April 2007, and through almost 4 years of monitoring, it has been observed that its performance is stable.

Keywords: *bridge, concrete girder, externally prestressed, CFRP tendons, monitor.*

Urban Viaduct in Povazska Bystrica, Slovakia

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A multi-span extradosed bridge that was built on the D1 motorway in Povazska Bystrica, Slovakia, is described in terms of architectural and structural solution and construction technology. The concrete deck is suspended on seven low pylons situated in the bridge axis. The deck is formed of a single box girder with large overhangs supported by precast V-shaped struts. The bridge was simultaneously cast in 2 × 7 symmetrical cantilevers originating from H-shaped piers. The bridge having a total length of 958 m was built within 22 months.
Keywords: multi-span; extradosed bridge; box girder; overhangs; cantilever construction; stay cables; internal ties.

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Teglvaerks Bridge – Copenhagen

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The new bridge connection between the islands Teglholmen and Sluseholmen in Copenhagen Harbour was advertised for prequalification in the summer of 2008 and six consulting firms were selected for participation in the design competition for the bridge link. The bridge is 100 m long between the abutments on the quays of the two islands. The centre span of 19,6 m consist of a bascule bridge span. The span length is chosen in order to provide a free navigational opening of 15 m width. The total width of the bridge is 18.5 m and includes two road lanes, two bicycle lanes and two pedestrian lanes. The two side spans on each side of the bascule span are 19,1 m and 19,6 m respectively, and the structures are post-tensioned concrete slab bridges. The bascule span is outstanding in the way, that the mechanical system provided by hydraulic anchor stays, is integrated in the structural system. The bascule span is designed as a box girder bridge with an orthotropic steel plate deck. The box girder is provided with triangular supports with a top level 6 m above the bridge deck. These triangular structures are connected with back stays in the shape of the hydraulic cylinders connected at the top of the triangle and anchored near the next support approximately 17 m from the bascule rotation link. The concrete spans are supported at the quay side abutments and on two sets of columns placed respectively 19,1 m and 38,7 m from the quayside. These column supports are circular steel tubes filled with reinforced concrete. The concrete filled steel tubes are drilled down into the limestone. The geometry of the triangular structures is balanced very accurately to assure the stability of the system when the hydraulic cylinders are retracted fully and the bridge floor is in the vertical position exposed to full wind load. The control tower for the bridge is located discretely apart from the bascule span outside the intermediate support for the side spans. It is connected with a small pedestrian bridge to give access to the operative personnel. The opening of the bridge is operated from the top floor in the control tower.

Keywords: *bridges, foundations, underground structures, steel, concrete.*

Extradosed Prestressed Concrete Bridge with High Strength Concrete, Japan - Yumekake Bridge

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Yumekake Bridge is an extadosed prestressed concrete bridge over Kumano River in steep ravine located near the World Heritage of Sacred Sites and Pilgrimage Routes in Kii Mountain Range in Japan. This bridge is the nation's first extradosed prestressed concrete bridge with high-strength and self-compacting cast-in-place concrete of specified design strength of 60MPa for the tower and the box girder. The high strength materials are also employed for the piers. This solution accomplished the slenderness and seismic resistance. This paper reports the special features of the bridge.

Keywords: *extradosed prestressed concrete bridge, high strength concrete, self-compacting concrete, cantilever erection.*

Eminent Structural Engineer

Kruno Tonković – Professor, designer, builder, Scientist and Visionary (1911–1989)

by Jure Radić, Prof. Dr., University of Zagreb, Croatia.

Recent PhD Abstracts

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