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Development of Hybrid Bridges: State of Arts and Conceptual Design

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Abstract: A state of the art of developments of the Hybrid bridges is presented focusing on steel-concrete composite bridges, considering the steel beam, concrete deck and connections developments. The analysis and design methods of composite bridge structures, connections, the reliability and life cycle of bridges, new bridge system forms and the use of alternative materials are reviewed with some possible applications. Conceptual ideas on new connectors form and its application in steel-concrete composite bridge structures also presented.

Key words: Bridge, composite bridge, connector, conceptual, perfobond

INTRODUCTION

The design and construction of bridge building were developed during thousands of years with different rates. The development of modern highway networks results an evolution of bridges accompanied with material of construction, form of structures and the design and analysis methods evolutions. The hybrid or composite structures was introduced to serve as a highly competitive type of bridge compared to the common types of bridges such as concrete and prestressed concrete bridges due to the reduction in weight and allowing a quick and cost effective erection. An extensive investigation in recent decades focused on development of hybrid bridges design and analysis methods, inventing new types of connection, enhancing bridge reliability and adopting an alternative forms and materials, such as Fiber Reinforced Polymers (FRP) and Inorganic Phosphate Cement (IPC), to form new types of hybrid bridges, in different countries. A review of development steps are explained as follow.

ANALYSIS AND DESIGN METHODS

Two types namely I-girder and Box-girder composite bridges are available (Fig. 1). The main design and analysis categories are performed through: 1) Adopting analytical method calculating structural stresses; 2) Computing response of section to different load histories using numerical methods such as finite element method. Design methods depends on using numerical methods or methods stated by codes depending on experiments by developing codes to design composite bridges as, Chinese Code, AISC and AASHTO, depending on developing numerical and analytical models accompanied

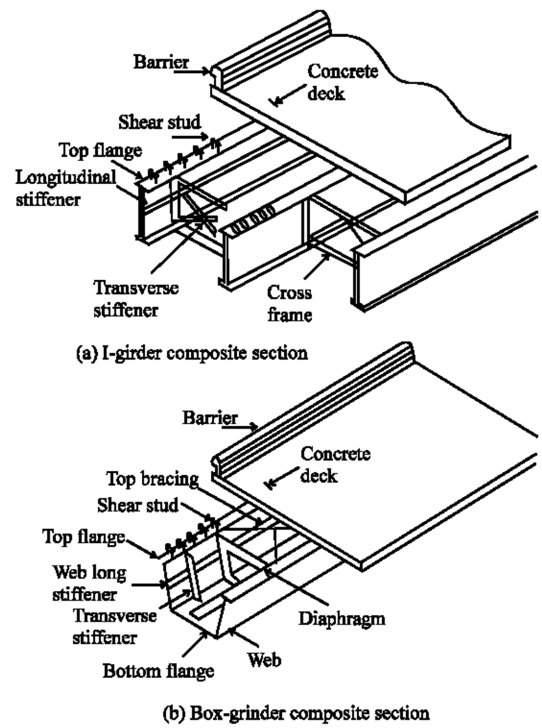

Fig. 1: Typical components of composite bridges (Chen and Duan, 2000) (a) I-girder composite section (b) box-girder composite section

with experimental tests, aiming to obtaining best simulation and most accurate results (Chen and Duan, 2000; AASHTO, 1994; AISC Comment-ary, 2005; AISC Specification, 2005).

The load carrying capacity is an important factor affects on composite bridge behavior and the nonlinear bridge's behavior, which investigated by different finite

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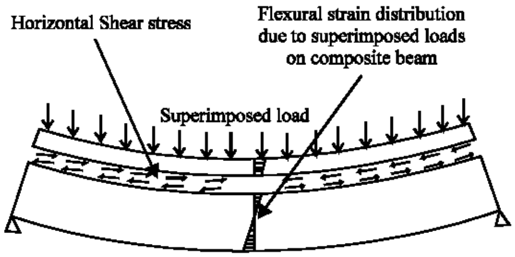

Fig. 2: Shear forces in composite action (Menkulasi, 2002)

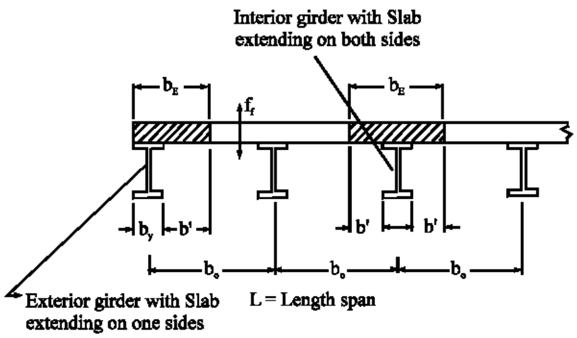

Fig. 3: Effective width b_E of composite beams

element models such as ADINA, ABAQUS, ANSYS and FORTRAN languages, developing different models, using various types of elements, an analytical method is also derived. The effects of secondary elements (barriers, sidewalks and diaphragms) on load capacity also investigated aiming to better understanding the bridge behavior and developing good and efficient method to get the most accurate results. The interaction between girder and deck slab were investigated considering the effect of partial and fully interaction at interface between steel beam and concrete slab on bridge's behavior (Fig. 2), investigating bridges flexural capacity (Eamon and Nowak, 2005; Menkulasi, 2002; Salmon and Johanson, 1990).

The effective width of composite bridge is an important factor. Designs mainly based on girder steel properties as girder shapes, thickness, yield stress of steel Fy, tensile strength of steel Fu, modulus of elasticity Es. The reinforced concrete bridge decks compressive strength fc', reinforcement properties and concrete modulus of elasticity E_C also affect the design, using transformed area of concrete calculate composite section properties with ratio ($n = E_S/E_C$), E_C estimated according to ACI or AISC-specifications (ACI 318, 1999; AISC Commentary, 2005; Salmon and Johanson, 1990). Width of top flanges comprised concrete slab and top steel beam flange known as effective width b_E, (Fig. 3), is the equivalent area carry compression force. The practical simplifications of effective width for design purposes are given by AISC, AASHTO LRFD, British (BS5400), Canadian, Chinese, Japanese Codes and Eurocode4 depends on span length. Finite element modeling also used to define composite bridge flange width, employing elastic and plastic modeling (AASHTO, 1994; AISC Commentary, 2005; Chen and Duan, 2000; Chiewanichakorn *et al.*, 2004; GBJ, 1988).

The effect of Load distribution in longitudinal and transverse directions with inelastic deformations, reactions and moments, on composite bridge behavior examined by numerical and experiments, bridge show a significant ability to redistribute force effects, considering the wheel load distribution factor comparing with AASHTO. The finite-element method used with various geometries and loading conditions, investigating distribution of flexural stresses, deflection, shears and reactions, deducing expressions for moment and deflection distribution factors. The continuity of the composite bridges producing advantages of, higher span to depth ratio, less deflection and higher stiffness, investigated by finite element, laboratory and field tests considering influence on longitudinal moments in girders, accounting for nonlinear structural behavior on negative moments regions using a numerical, analytical and experimental procedures. Studies also performed for prestress continuous composite bridges in elastic and plastic ranges. The long term behavior of concrete deck slab also investigated aiming to understand the full behavior of composite bridge system, by *in situ* measurements, laboratory tests and numerical simulations, establishing criteria based on restraint coefficient showing the most critical tensile stresses and the effects of casting sequence. The creep and shrinkage effects for composite box girder bridge with placing sequence investigated developing a numerical model by layer approach, experiments and field examinations for actual bridges. The dynamic response of composite bridges was investigated by different finite element models aiming to better understanding the dynamic effects of bridges, as the diaphragm effects, identification the characteristic properties, the natural frequencies and the dynamic impact factors under truck loading (AASHTO, 1994; Jurkiewiez and Hottier, 2005; Ryu *et al.*, 2004; Samaan *et al.*, 2002; Tedesco *et al.*, 1995).

CONNECTION OF COMPONENTS

Nowadays, different types of shear connectors available, such as: Stud; Channel; Angle; Spiral; Tendon; Perfobond; and T-shape connectors (Fig. 4-7). Divided to rigid and flexible connectors, depending on shear forces distribution and functional between strength and deformations. Most codes consider stud and channel

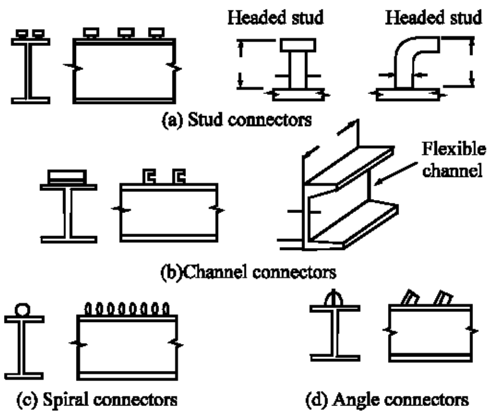

Fig. 4: Stud, channel, spiral and angle connectors (Salmon and Johanson, 1990)

Fig. 5: Stud, tendon and steel connectors (GBJ, 1988)

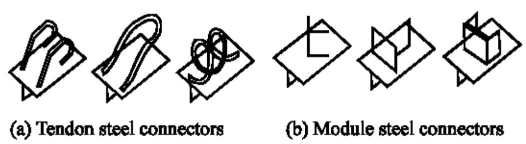

Fig. 6: Tendon and mould steel connectors (Liu, 2004) (a) Tendon steel connectors (b) Mould steel connectors

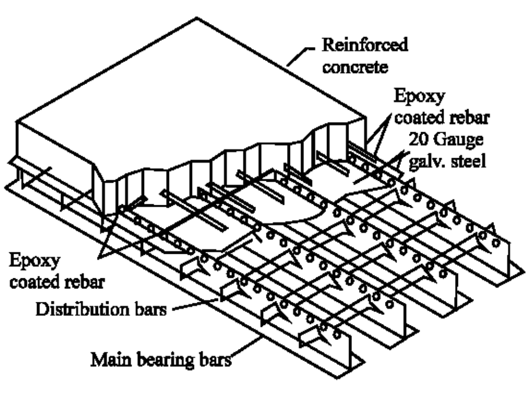

Fig. 7: Alternative shear connector (Higgins and Mitchell, 2001)

connectors only. Shear connectors are important details investigated and developed through different researches with different type of loads developing different shear connector types. New connection forms between steel girder and concrete slab also considered (GBJ, 1988; AISC Commentary, 2005; Valente and Cruz, 2004).

A stiffness and strength degradation and a correlation studies with push-pull tests on shear connectors performed, the strength, mechanism of failure and basic criteria used to define shear connector strength investigated by analyzing expressions and recommendations given by Eurocode4, giving commentary on strength of connectors. The provision of adequate shear connection between tension and compression-resisting components of flexural members is essential to robust performance of such structural members. Ductility requirements were also investigated defining ductility in terms of behavior of composite cross-sections considering performance with both ductile and non-ductile connection. However, some connections' consideration required, high ductility and capacity. Finite element analyses used to investigate the required level of connection ductility on connections, considering slip requirement (Patrick and Bridge, 1988; Ranković and Drenić, 2002; Salmon and Johanson, 1990; GBJ, 1988; Liu, 2004; Valente and Cruz, 2004). Obviously, the connection largely influences global behavior of composite bridges, connector modeling is a key issue in the analysis of such types of structures. The effect of partial restraints on the response of composite bridges was investigated using spring, accounting shear deformation by displacement and force based elements considering bond-slip between element components. Load-slip behavior and shear capacity of stud obtained experimentally by push-tests simulated by finite element model, a procedure suggested to obtain connector stuffiness. The fatigue and cyclic load affect the behavior of composite bridges by affecting on shear connectors, which investigated to estimate the reduction in strength by analytical and experimental studies investigating fatigue and reliability characteristics of connection, estimating bridge's behavior (Liu, 2004; Johnson, 2000; Salmon and Johanson, 1990; Wang, 1998).

A new connector types innovations as Alternate Shear Connector (ASC), (Fig. 7), developed and tested by static and cyclic loads, aiming to create full composite action, found that, shear connection location not control fatigue behavior of deck in positive bending and no fatigue cracking of steel grid was observed in negative bending (Higgins and Mitchell, 2001). The development and implementation of large stud diameters also presented, aiming to increasing bridge erecting speed and future deck replacement and reduce the damage possibility of studs and girder top flange during deck removal, which also placed in one row freeing up most of top flange width and improving safety conditions for field workers. Another new types of connector namely perfobond connectors were presented. A horizontal shear connectors without welding, also presented for composite beam showing behavior similar to classical one, great ductility, low relative movements at steel-concrete interface (Liu, 2004; Shim *et al*., 2004; Valenteand Cruz, 2004).

RELIABILITY AND LIFE CYCLE

The reliability and life cycle of composite bridge designed by AASHTO's methods for maximum load, overloading and fatigue, measuring ultimate flexural capacity limit state in terms of reliability index, using Monte Carlo simulation method as a function of compactness, method of design, beam spacing, span length and section size, which examined by stochastic finite element method and investigated considering life cyclic and maintenance effects on total life cost of bridges to select optimum strategy in the face of uncertainties and fiscal constraints identifying optimum maintenance scenario (AASHTO, 1994; Kong and Frangopol, 2004; Kong and Frangopol, 2005).

NEW COMPOSITE BRIDGES FORMS

A new structural forms of composite bridges were invented and suggested for use in last decades, such form of composite bridges were used in Japan, using concrete filled pipes or rolled H-girders, having higher strength and ductility, restricts local buckling. Partially encased composite I-girders bridges also investigated experimentally and analytically. Experimental investigation on steel tube filled with reinforced concrete bridge girder (Fig. 8) also conducted (Mossahebi *et al*., 2005; Nakamura and Narita, 2003).

NEW BRIDGE MATERIALS

The development of Fiber Reinforced Polymer (FRP) material and their usage as a structural members in bridge construction as lighter, more durable alternatives to steel and concrete also investigated by finite element, analytical and experimental study on cellular box decks and wide-flange I-beam stringer, predicting an efficient FRP sections and simplified design equations for new and replacement highway bridge system. A new materials such as Inorganic Phosphate Cement (IPC) also used in composite bridges construction and investigated to form a new hybrid bridge system, analytically and by finite element (Lin *et al*.,1996; Roover *et al*., 2003).

CONCEPTUAL DESIGN IDEAS

Aiming to enhance composite action of steel-concrete composite bridges, a new shape of perfobond connectors proposed to be numerically and experimentally investigated in China, depending on the analysis of shear affects on the interface between steel and concrete and the shape of failure of stud connectors, assuming that such connector will improve the interaction between the steel girder and the concrete slab. Two shapes of perfobond connectors are suggested to be investigated (Fig. 9), make use of: more main and secondary transverse reinforcement pass through holes of connectors without bent; Producing better interaction between concrete and connectors by increasing length of interaction and increasing the area of concrete inside the connector.

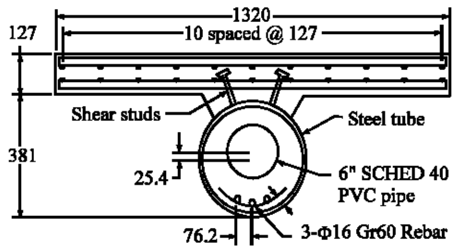

Fig. 8: Steel tube filled with reinforced concrete (Mossahebi *et al*., 2005)

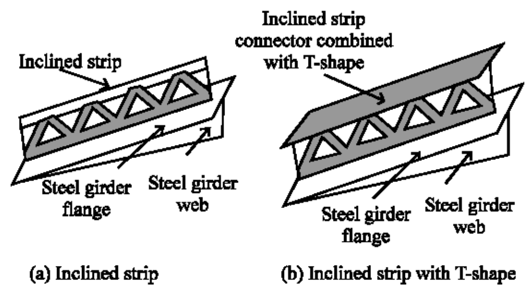

Fig. 9: Shear connectors suggested

CONCLUSIONS

The main categories researches focused on developing the hybrid bridges are summarized in the following: Analysis and design methods of composite bridge; The connections between composite bridges components; Reliability and life cycle of bridges; Establishing new bridge forms and Developing an alternative materials.

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