# COMPOSITE ACTION IN BRIDGE I-GIRDER SYSTEMS

by

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This thesis investigate the development of new connection systems for composite action in both concrete and steel girder bridges. The new systems will enhance and accelerate the replacement process of concrete bridge decks, and provide sufficient composite action to resist the horizontal shear at the girder-to-deck interface. The new systems include a debonded interface with formed shear key protruding from the precast girders and steel connectors for concrete girders; 1-$^1/_4$ in. diameter steel shear studs and a new "dovetail" shaped connector plate for steel girder construction.

Test program consisting of horizontal shear push-off specimens, lab size beams, and full scale girders was conducted on all proposed connection schemes. Test results show that the debonded shear key system with a steel connectors spaced at 24 in. along the length of the girder provides sufficient horizontal shear resistance utilizing the shear friction theory. The 1-$^1/_4$ in. diameter steel shear studs appears to have high fatigue resistance and higher $\alpha$ values as compared to both AASHTO Standard and AASHTO LRFD Specifications. The ultimate strength capacity of the 1-$^1/_4$ in. studs found to be twice the

capacity of the conventional 7/8 in. diameter studs. The testing conducted so far on the steel dovetail plate connector has demonstrated the viability of the new system. Its strength was found to depend upon the amount of reinforcement transverse to the plate connector. The dovetail connector does show a merit as a possible standard composite connection method for all sizes of steel girder bridges. Design criteria and procedures for the new connection systems are presented.

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$a$ = depth of equivalent compression zone at nominal strength

$A_{bs}$ = area of concrete dowel in shear

$A_{cc}$ = area of concrete in the plane of the connector

$A_{DT}$ = area of one dovetail connector

$A_{sc}$ = cross-sectional area of a stud shear connector

$A_{sk}$ = area of shear key at its' base

$A_{st}$ = area of steel

$A_{hole}$ = cross-sectional area of hole

$A_{vf}$ = area of vertical steel reinforcement crossing the interface

$b$ = width of section

$b_v$ = width of interface

$c$ = cohesion coefficient

$C$ = total compresion force acting in the section

$d$ = distance from extreme compression fiber to centroid of steel

$d_s$ = diameter of stud

DL = bridge dead load

$E_c$ = concrete modulus of elasticity

$f_u$ = ultimate stress

$f_y$ = yield strength of non-prestressed steel

$f'_c$ = concrete compressive strength

$f_{cl}$ = clamping stress

$f_{max}$ = maximum applied stress

$f_{min}$ = minimum applied stress

$G$ = shear modulus

$h$ = overall depth of the member

$I$ = moment of inertia of the section

$I_{cr}$ = cracked moment of inertia

$l_s$ = effective bar length in shear

$l_t$ = effective bar length in tension

LL = bridge live load

$M_{cr}$ = cracking moment

$M_n$ = nominal midspan moment

$M_u$ = ultimate midspan moment

$N$ = number of fatigue cycles

$P$ = applied force

$P_c$ = net compressive force normal to shear interface

$P_y$ = tensile force in the connector

$P_{xy}$ = shear force in the connector

$Q$ = first moment of area

$Q_{cr}$ = shear stud critical ultimate load

$Q_n$ = shear stud nominal horizontal shear stress (AASHTO LRFD)

$q_u$ = ultimate strength

$t$ = height of shear key

$s$ = steel spacing

$S_c$ = spacing of shear connectors

$S_{sk}$ = spacing of shear keys

SF = ultimate shear force per hole in Perfobond Strip or per one Dovetail connector

$S_r$ = applied stress range

$S_u$ = shear stud ultimate horizontal shear strength (AASHTO 15th Ed.)

$V_n$ = nominal vertical shear force

$V_u$ = ultimate vertical shear force

$\nu$ = horizontal shear stress

$\nu_{nh}$ = nominal horizontal shear stress

$\nu_{uh}$ = ultimate horizontal shear stress

$w$ = width of dovetail at its' base

Zr = shear stud allowable range of shear force

$\Delta$ = displacement

$\alpha$ = fatigue coefficient for shear studs

$\delta$ = local coefficient of friction

$\varepsilon_x$ = tensile strain in the x direction

$\varepsilon_y$ = tensile strain in the y direction

$\phi$ = reduction factor

$\gamma_{xy}$ = shear strain

$\lambda$ = constant used for the effect of concrete density

$\mu$ = friction coefficient between the two surfaces

$\mu_e$ = effective coefficient of friction

$\nu$ = poisson's ratio of steel reinforcement

$\rho_v$ = area of reinforcement crossing the surface per unit area

$\sigma_y$ = tensile stress

$\tau_{xy}$ = shear stress

$\omega = \dfrac{\rho_v f_y}{f'_c}$

# Chapter 1

# Introduction

The objective of this research is to develop new connection systems for both concrete and steel girder bridges which facilitate future bridge deck replacement and provide full composite action. Composite action in structures may be considered as the interaction of different structural elements and may be developed using either different or similar structural materials, in which these materials act together as a single unit under superimposed load. The most common composite construction in bridges consists of cast-in-place (CIP) reinforced concrete slab on either a precast concrete or steel beam.

The composite construction is smaller, shallower, and lighter than non-composite construction and thus leads to overall cost savings. The most common connection between the slab and the steel beams are welded studs and C channels. For concrete girders, extended steel shear reinforcing, and the natural bond between the concrete deck and the concrete girder are the most common connections.

The increasing traffic demand on bridges in the United States during the last 20 years and the use of deicing salts have caused increased bridge deck deterioration which, in turn, raises the need for deck replacement. In areas of heavy traffic volume, deck replacement

often must be performed in a short period of time. A girder-to-deck connection which facilitates rapid deck replacement is, therefore, a high priority.

Extra effort and care is needed to remove the deteriorated concrete from around the connectors used to provide the composite action and from the girder top flange. This is especially evident in concrete girder bridges where the concrete girder surface is bonded to the concrete deck. Deck removal could be enhanced if the bond between the concrete girder top flange and the concrete deck could be eliminated by a debonded mechanical system, such as debonded shear key interface with steel ties crossing the interface.

Steel studs are the most common method for providing composite action between the concrete deck and steel girders. The studs are welded to the top flange through an efficient stud-gun welding process. The relatively small spacing between the studs along the length of the girder or the number of studs per row can sometimes slow deck removal. If the spacing between studs is increased to the Specification limitations or the number of studs per row is decreased, through the use of larger diameter studs, the removal process could be enhanced.

The connection systems developed in this study include those for both steel and concrete girders. The objective of these connections is to speed up deck removal without damaging the connectors or the girder top flange, and to provide the full composite action and the horizontal shear strength needed in the girder-to-deck connection.

A test program was developed to evaluate the horizontal shear strength of the proposed connections through the use of push-off specimens, lab size beam specimens, and full