SEISMIC RESILIENCY OF BRIDGE COMPONENTS CONSTRUCTED WITH CONCRETE-FILLED STEEL TUBES - FROM REASERCH TO IMPLEMENTATION

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Abstract:

Concrete-filled steel tube (CFST) components are used for bridge components in high seismic regions and where the site consists of soft or liquefiable soil or has the potential for lateral spreading. The steel tube provides casing for concrete; and the concrete prevents local buckling of the steel tube casing. The steel tube also prohibits excessive concrete spalling, allows for composite column action and adds significant stiffness to bridge bents compared to traditional concrete bent construction. CFST columns and piles have higher flexural, axial, shear strengths, and stiffness than the same sized reinforced concrete component which is beneficial in seismic applications. The composite action of the casing and concrete will reduce the size and improve the seismic performance. This paper focuses on the CFST research and implementation in bridge projects. The objective of the research was to investigate the CFST pier connections through testing of bond mechanisms with large-scale connection tests, analytical analysis, and create design expressions for each connection type used in bridge construction. Research shows that redesign of conventional bridge components with CFST can result in smaller columns or piles, improved seismic performance and significant savings.

Keywords: *Bridge, Seismic, CFST, Ductility, Column, Pile/Shaft*

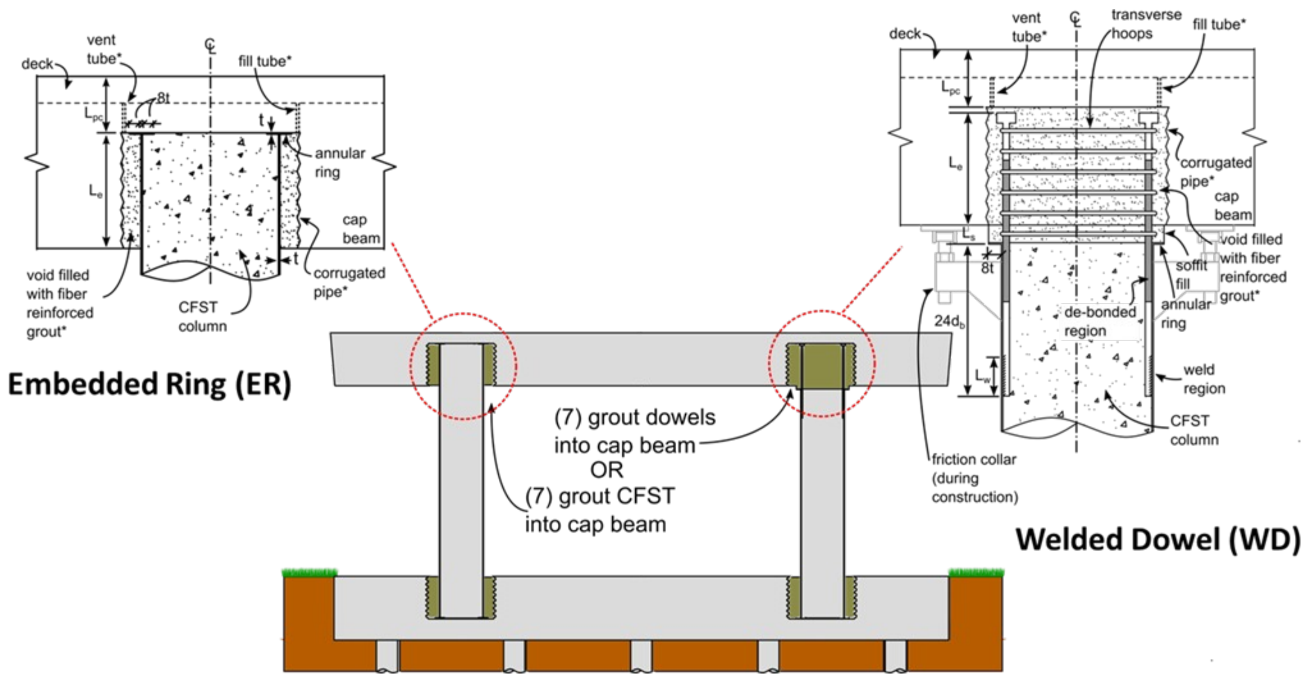
Introduction

The concrete-filled steel tubes (CFST) are used as ductile elements as part of an earthquake-resisting system. CFST have been shown to offer strength and stiffness beyond a conventional reinforced concrete (RC) member. Recent research has shown that CFST members can sustain large cyclic drifts with minimal damage. The design methods herein regarding concrete-filled steel tubes are largely based on study, testing and recommendations compiled by this experimental research.

The concrete for CFST members was low-shrinkage, self-consolidating concrete. The nominal concrete strengths were 6 ksi and 10 ksi. This represents structural concrete with a minimum specified strength of 4 ksi, and an expected strength 25 percent to 50 percent larger.

The first CFST-to-cap connection type involves an annular ring attached to the top of the CFST, and is partially embedded into the pile cap. This anchored connection resists flexural loading from the pile through strutting action to the bottom of the pile cap (resulting from the portion of tube of the CFST that is in tension) and the top of the pile cap resulting from the portion of tube of the CFST column that in compression. Tests show this connection is both simple to construct and fully effective in transferring flexure. The second CFST-to-cap connection type requires a circular reinforcing cage with headed longitudinal bars that extend into the concrete cap. The CFST is discontinued just below the cap. This connection type is beneficial for plastic design in that it allows the designer some flexibility in the plastic demand that must be resisted by the cap.

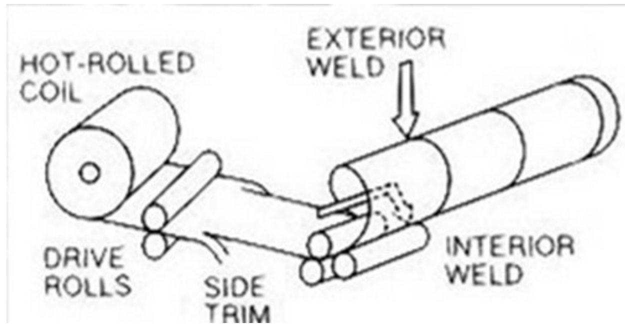
Transition connections between RC shafts and CFST shafts have not been tested and considerable analysis has been performed. Overstrength factors for capacity protection design of adjacent members and joint shear design at connections were not addressed in the research.



Materials requirement for CFST

The concrete for CFST is class 5000P and Steel tubes shall conform to API 5L Grade X42 or X52 for longitudinal seam welded or helical (spiral) seam submerged-arc welded tube, ASTM A 252 Grade 2 or 3 for longitudinal seam welded or helical (spiral) seam submerged-arc welded tube, ASTM A 572 or ASTM A 588 for longitudinal seam welded tube.

When a CFST will be used as an earthquake resisting element and is expected to develop a plastic hinge, the steel tubes is fabricated from steel meeting the mechanical and chemistry requirements of AASHTO M 270 GR 50 (ASTM A 709 GR 50) regardless of fabrication method. For capacity protected members at the extreme event limit state, expected material properties may be used to determine the expected nominal moment capacity. The expected yield strength, Fye, for steel tubes is taken as 1.1Fy.

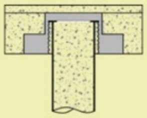
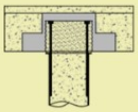
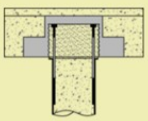
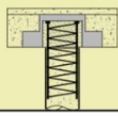


CFST Dimensions

The minimum tube wall thickness shall not be taken less than ⅜ inch at the time of installation. To develop the full plastic capacity of CFST members, it is necessary to ensure that local buckling does not occur prior to development of the strength of the tube. Therefore, the following D/t limits are recommended:

For members subjected to elastic forces	**For members subjected to plastic forces**
$\frac{D}{t} \leq 0.22\frac{E}{F_y}$	$\frac{D}{t} \leq 0.15\frac{E}{F_y}$

Where D is the outside diameter of the tube (in.), and t is the wall thickness of the tube (in.). Both D and t are adjusted for corrosion as defined in Section H.

Connection Type	Loading Direction	D (in)	t (in)	Tube Type	Axial Load (P/Po)
Embedded Ring 	Transverse	20	0.25	Spiral Weld	0.1
	Transverse	24	0.25	Straight Seam	0.05
	Longitudinal	25.75	0.25	Spiral Weld	0.1
	Longitudinal	24	0.25	Straight Seam	0.05
Welded Dowel 	Transverse	20	0.25	Straight Seam	0.1
De-bonded Welded Dowel 	Transverse	20	0.25	Spiral Weld	0.1
	Longitudinal	20	0.25	Spiral Weld	0.1
Reinforced Concrete 	Transverse	20	0.25	Spiral Weld	0.1

CFST Effective Stiffness

Effective stiffness, EI_{eff}, of circular CFST is used to evaluate deflections, deformations, buckling resistance, and moment magnification. The effective stiffness factor, C’ is defined as:

$$EI_{eff} = E_s I_S + C' E_c I_c$$

$$C' = 0.15 + \frac{P}{P_0} + \frac{A_S}{A_S + A_C} \leq 0.9$$

P_0 is the nominal compressive resistance (crushing load) without moment, P is the factored axial load effect, and A_s is the combined area of the steel tube and steel reinforcing.

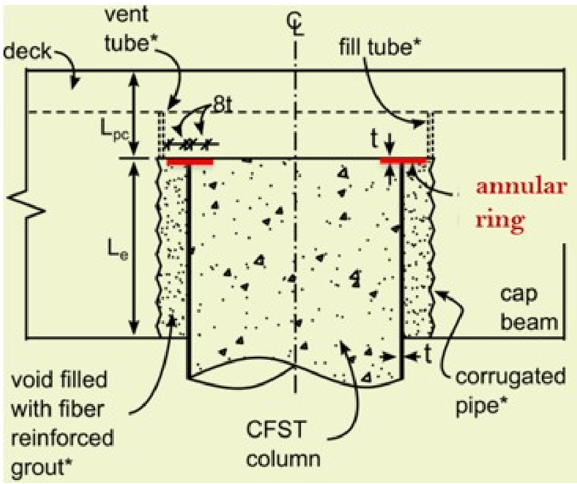
$$P_0 = A_{st} F_{yt} + A_{srl} F_{yrl} + 0.95 A_c f'_c$$

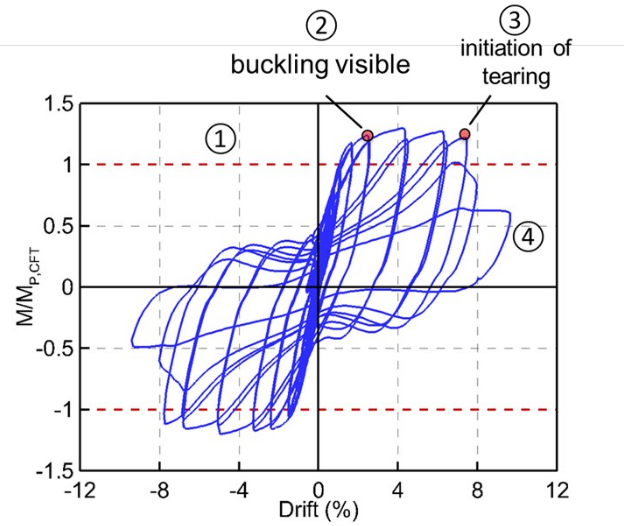
A_{st} is the area of the steel tube.

An annular ring is welded to the end of the tube to provide anchorage and stress distribution. The ring is made of steel of the same thickness and grade as the steel tube. The ring shall extend outside and inside the tube a distance of 8t, where t is the thickness of the tube after considering corrosion.

The ring shall have 1” diameter vent holes near the connection to the CFST to ensure concrete consolidation under the annular ring. There is a minimum of 4 holes equally spaced on the ring both outside the tube and inside the tube.

Annular Ring Connections





The CFST tube and the annular ring is embedded into the pile cap a distance, le, as defined in the following equations. To develop the yield strength of the CFST and plastic behavior is not expected, then the embedment length shall satisfy:

Yielding	**Seismic**
$L_e \geq \sqrt{\frac{D^2}{4}+\frac{DtF_y}{8\sqrt{f'_{c,cap}}}}-\frac{D}{2}\ (psi)$	$L_e \geq \sqrt{\frac{D^2}{4}+\frac{DtF_u}{6\sqrt{f'_{c,cap}}}}-\frac{D}{2}\ (psi)$

CFST Punching Shear Requirements

The pile cap shall have adequate concrete depth, h, above the steel tube to preclude punching through the pile cap. The value of h shall satisfy:

$$h \geq \sqrt{\frac{D^2}{4}+\frac{C_c+C_s+\boldsymbol{P_{axial}}}{3*0.0316*\boldsymbol{\pi}\sqrt{f'_{c,cap}}}}-\frac{D}{2}-L_e \geq \boldsymbol{8t}$$

$$(f'_{c,cap}\ in\ ksi)$$

Cc and Cs are the compression forces in the concrete and the steel due to the combined bending and axial load as computed by the plastic stress distribution method for the most extreme load effect at the appropriate limit state.

Concluding Remarks

- Spiral Weld provides mechanical interlock and superior bond capacity
- CFST bridge columns and connections are efficient relative to RC,
- CFST columns are stiffer and stronger for a given cross section. Material savings between 20 and 60%
- The embedded connection is applicable to cap beam and foundations and capable of developing the full composite flexural strength of the CFST
- Design expressions have been implemented in the WSDOT Bridge Design Manual
- CFST is a viable solution for rapid construction of bridges

References

1. Concrete Filled Steel Tube Bridge Pier Connections – An ABC Solution, B. Khaleghi, D. Lehman, and C. Roeder, FIU Webinar, http://www.wsdot.wa.gov/publications/manuals/m23-50.htm