ABC-UTC April 2021 Research Seminar: Connections for Concrete-Filled Steel Tubes in Bridge Applications		
#	**Questions**	**Responses**
	Research	
1	a) What material model was used for modeling the concrete? b) Did you use element erosion in your model? c) How was the contact between the steel and concrete defined?	a) Concrete Damage Plasticity Model (CDP model or MAT273 in LS-Dyna) was used. b) Element erosion was not considered, but the concrete damage level was computed. c) Friction base models with contact surfaces were used.
2	What modulus inputs for the concrete-filled steel tube did you use? Were these calculated or measured?	Modulus inputs were measured by comparing to experimental results.
3	What is the resiliency if corrosion of the confinement reinforcing is occurring? How much reliance is there on the steel reinforcing?	Steel is very essential for any application requiring ductility from concrete. No steel - no ductility. If the CFST is in a region where corrosion can occur, one can use hot-dip galvanization, various wraps or coatings, or allow a corrosion allowance for lost material.
4	Did you use the Peridynamic approach for fracture mechanics in your research?	No. We did not use this approach in our research.
5	What is the bond stress-slip law that was used in LS-DYNA to simulate the bond between the steel tube and the concrete fill?	A friction-based law was used. The reinforcement-concrete interface was modeled using the “BEAM_IN_SOLID” function with the bond-slip model.
6	Was any comparison made between the welded rib reinforcement and additional hoop reinforcement near the top of the CFST?	Not In these analyses, but it has been studied. The confinement provided by any spiral is trivial compared to even a thin tube.
7	What class of concrete (f'c) is used for fill in the steel tubes?	We typically use concrete between 5 and 10 ksi. Self-consolidating, low-shrinkage concrete has advantages that we frequently employ.

8	Michel Bruneau did research on the concrete steel tube bond. Can you speak about his findings?	I am familiar with his work. The number of tests he did were quite small, but I think the results were comparable to our results.
9	Can you discuss your recommended needs for research improvement of CFSTs?	I think the use of CFSTs always raises questions about connections. Circular CFSTs seem to raise more questions because one does not immediately see how connections will work with them. I think experimental verification of some connections that are used is particularly needed.
	Applications	
10	Where are CFSTs currently being used?	A number of states use them in one form or another, including Washington, Alaska, Idaho, California, and others. Often they are not used to their maximum benefit.
11	Could the application of these tubes filled with concrete be applied in highly seismic countries like Peru?	Yes. All of our research focuses on applications for high seismic zones. However, tubes may not be readily available in Peru.
12	What is the composite flexural capacity of the concrete-filled steel tubes (CFSTs)?	We normally calculate it by the plastic stress distribution method, and it is quite accurate. However, for pure flexure, CFST's moment capacity is only slightly greater than the moment capacity of the hollow tube if buckling of the tube is prevented. CFSTs are very efficient in composite behavior if at least a small compressive force is added.
13	What is the capacity of CFSTs based on steel alone versus confined concrete? Is a reinforced concrete section with a steel tube "composite" without studs?	See Item 12. CFSTs are much, much stronger than hollow steel when axial compression is added. Studs are not normally needed if there is a modest bending moment on the CFST. *I would never use studs with CFSTs. If help is needed with stress transfer, a steel rib should be added inside the tube.*
14	Do you have information about the minimum depth of embedment of the pile into the foundation to achieve a full moment connection?	Yes. It depends on how you embed the pile. But for a start, see "Lehman, D.E. and Roeder, C.W. (2012) "Foundation Connection for Circular Concrete Filled Tubes," Journal of Constructional Steel Research, Vol. 78, November 2012, pgs. 212-25, Elsevier."

15	At what depth is the steel pipe pile strength fully developed below the concrete cap, e.g., three diameters (3D)?	This depends on how you make the connection, but it can be much less than 3D. See "Lehman, D.E. and Roeder, C.W. (2012) "Foundation Connection for Circular Concrete Filled Tubes," Journal of Constructional Steel Research, Vol. 78, November 2012, pgs. 212-25, Elsevier."
16	What are some criteria for using provisions of AASHTO LRFD 6.9.6 instead of the provisions of AASHTO LRFD 6.9.5?	AASHTO LRFD 6.9.6 is for composite behavior and AASHTO LRFD 6.9.5 is not.
17	What is the cost effective spacing for CFSTs?	The spacing should be as needed.
18	Can you discuss the availability, specifications, and unit costs for CFSTs?	Many companies make steel tubes in the U.S. and abroad. There are a number of ASTM standards related to them. For steel tubes, we recommend using American Petroleum Institute (API) 5L as the controlling standard for seismic design.
19	Will this presentation cover filler beam?	I don't understand what you mean by "filler beam," but CFSTs can be used for flexure.
	Questions during Seminar	
20	For your seismic testing, did you use 3-D excitation waves from actual seismic events or just a general equivalent static load?	We used both in our seismic testing.
21	What about the cost of CFSTs as opposed to a reinforced concrete (RC) column?	Costs are hard to address. CFSTs will use more expensive steel and labor, but CFSTs will use a lot less steel and concrete overall.
22	What about the durability of CFST in comparison to the columns in reinforced concrete (RC)?	CFSTs are much less likely to be damaged by blast or impact than reinforced concrete (RC). If corrosion is possible, you want to use coatings, wraps, or galvanization in the corrosive region. Beyond this, I think CFSTs are much more durable than RC.

23	Based on your presentation, both steel and concrete will work together for the shear and moment. Is there any connections between the concrete and the steel tube?	We have developed design methods and evaluated them for multiple connections. See "Lehman, D.E. and Roeder, C.W. (2012) "Foundation Connection for Circular Concrete Filled Tubes," Journal of Constructional Steel Research, Vol. 78, November 2012, pgs. 212-25, Elsevier." and "Stephens, Max, Berg, Lisa, Lehman, Dawn E. and Roeder, Charles W. (2016) "Seismic CFST Column-to-Precast Cap Beam Connections for Accelerated Bridge Construction," Journal of Structural Engineering, ASCE, Reston, VA, DOI: 10.1061?(ASCE)ST.1943-541X.0001505."
24	What kind of surface is best for shear transfer between the concrete and the steel?	You can sandblast the surface if you wish, but normally we use the surface as it comes. We have greased the interface in some cases and still achieved composite resistance.
25	Can you use shear studs on the outside of the tube to attach to a cast-in-place foundation around the CFST?	I would not recommend it. I would recommend a flange on the end of the tube. It will develop the full resistance more quickly over a shorter length.
26	The strength of CFSTs is much greater than reinforced concrete members, and CFSTs are composite structural elements. Can you comment on the ductility regarding the seismic capacity and the damping value as well?	The ductility of CFSTs matches or exceeds that of reinforced concrete. The only way to get ductility from concrete is through steel.
27	For design, what provisions are made for long-term section loss of the casing or confinement?	The AASHTO specifications have recommendations for loss of section due to corrosion.
28	How is the cost of CFSTs compared with its corresponding reinforced concrete (RC) member?	The cost of the pile is not the issue. The CFSTs can develop the resistance with less material, so there is potential savings there. A CFST pile can often be built with a smaller crane than required for precast concrete piles due to its lighter weight. There are huge potential savings there. The labor required for CFSTs may be more costly than the labor required for RC, but you should have fewer hours of this labor. You need to look at the whole picture when determining costs.

29	Do you recommend driving the steel tube for the foundation element to maintain bending capacity from the soil, or cut and drop the tube, then backfill?	Both installation methods can be done. It depends on the job and equipment available for the work.
30	How thick is the flange in the embedded ring connection?	We recomment the same thickness as the wall of the tube.
31	What are access concerns for welding inside the tube for the welded dowel connection?	For large diameter tubes, it is no problem. For smaller diameter tubes, gas fumes for the welder are a concern. For very small diameter tubes, it is difficult to do this.
32	Have you seen any issues due to thermal expansion of the steel tube with the embedded ring connection?	No. Once the steel is buried inside the concrete, the temperature of the steel and concrete are the same. The coefficient of thermal expansion of the steel and concrete are not that different.
33	Regarding the welded dowel connection (Slide 29), how constructable is it to weld dowels to the inside face of the tube?	It is very constructable with large diameter tubes. It is not constructable with very small diameter tubes (less than 12 inches). The bars are only welded at most over the last couple of feet in the tube.
34	Have you looked at CFSTs for seismic retrofits, specifically, an interior bent with driven pipe piles welded to a double H-pile cap?	We have not looked at anything like you have described.
35	If CFSTs are used as columns for the bridges in locations with a high earthquake activity, the plastic moment would be huge. Can you comment on the design of the foundations since they would need to be designed using the overstrength moment and shear of the CFST columns?	If the CFST has too large a moment capacity, use a smaller diameter column. The overstrength for a CFST will likely be smaller than the overstrength for a reinforced concrete column.
36	What about corrosion issues, particularly in areas using de-icing salts? The steel shell is exposed. Does this result in a shorter life-span than a RC column, knowing that many owners do not have a robust maintenance painting program?	In those conditions, RC columns will also corrode. The de-icing salt and moisture will penetrate the concrete, corrode rebar, and spall the cover. There are coatings and wraps that can be used to prevent corrosion. Steel tubes have been used in offshore platforms for many years. Corrosion can be controlled. Skipped maintenance is never a smart idea for CFSTs, RC, and any other material.

37	For the connection that has a gap at the end of the steel tube and rebars extending into the connected members (cap and foundation), how is the capacity of CFST columns different from that of reinforced concrete columns?	When the steel tube does not penetrate the concrete cap, the connection is a reinforced concrete connection. This was done because that is what some engineers want. A CFST connection that penetrates the cap is a much stiffer and stronger connection.
38	For the welded rebar specimen, is the total area of the rebar equal to the area of the cross section of the steel tube? if not, what is the ratio?	The ratio is whatever you want it to be. The only reason to use this connection is to assure that you have a weaker connection at one end. This is what some engineers want for seismic design.
39	What concrete model have you used? Have you been able to validate the finite element model (FEM) concrete model with your research?	We use the Concrete Damage Plasticity Model (CDP model or MAT273 in LS-Dyna). All of our models were validated by comparing to experiments of other researchers and our experimental research.
40	Are sample details of ribs, ring connections, welded bars to CFSTs, etc., available if we want to use this in practice?	I refer you to a couple of papers: "Stephens, Max, Berg, Lisa, Lehman, Dawn E. and Roeder, Charles W. (2016) "Seismic CFST Column-to-Precast Cap Beam Connections for Accelerated Bridge Construction," Journal of Structural Engineering, ASCE, Reston, VA, DOI: 10.1061?(ASCE)ST.1943-541X.0001505."; seismic performance. Report for the California Department of Transportation. Report Number CA12-1972; 2012." "Stephens, M., Lehman, D. and Roeder, C. (2016) “Design of CFST Column-to-Cap Beam Connections for Moderate and High Seismic Regions” Engineering Structures 122:323-337 September 2016 DOI: 10.1016/j.engstruct.2016.05.023' and a report written for CALTRANSæ Lehman DE, Roeder CW. Rapid construction of bridge piers with improved seismic performance. Report for theæ California Department of Transportation. Report Number CA12-1972; 2012."
41	Were the two columns concreted at the same time, with the same batch of concrete? This question is regarding the ongoing research project (2014-present).	No. They were nominally the same concrete, but they were not the same batch or cast at the same time. Those specimens were so large that at least one required more than one truck load of concrete. That specimen weighed more than 15 tons.

42	What is cost comparison between reinforced concrete and CFSTs for similar diameters?	If they are the same diameter, the CFST would likely be more expensive, but it would be much stronger.
43	Is there data on long-term use of CFSTs in highly corrosive conditions?	No, but there is data for steel in highly corrosive conditions. Steel offshore platforms that were built 70 years ago in salt water are still in service.
44	How would you fix the bottom end of an embedded ring connection into, say, rock?	You do not need or want a flange if you are putting the tube into a rock socket. Use the flange when anchoring the tube into a concrete pile cap or pier cap. For a rock socket, slip the tube in place, grout it into the socket, and fill the tube with concrete.
45	Can you comment on the cost comparison with regard to both the construction and maintenance cost through the life of the structure?	We do not have this information.
46	Is there publicly available software to generate the axial load-moment (P-M) interaction curve for CFSTs?	The equations in the AASHTO LRFD Specification would do it for you if you wrote them into a spreadsheet. I have a spreadsheet that I made, but I do not know of anything commercially available.
47	Is there any reinforcing steel in your CFSTs?	Except possibly at the connections, there is not internal reinforcement in the CFSTs.
48	The results for CFSTs are quite satisfactory. However, in one case the steel is inside as in reinforced concrete (RC) columns, and in CFSTs the steel is outside. Will corrosion play an important role in choosing between the RC and CFST? How much research has been done in this field?	We have tested a few CFST members that were galvanized. Steel corrodes. Steel rebar corrodes. Rebar inside a RC column corrodes. At least with a CFST you can see the corrosion and deal with it. With RC you may not see the corrosion until significant damage has occurred.
49	Is a reinforcement cage used in the middle of the CFST?	No reinforcement cage is used in the middle of the CFST.
50	For piles, how do you get the axial resistance since skin friction is usually neglected by Caltrans for steel piles?	If you neglect skin friction, you need to rely on end bearing. But neglecting skin friction is an assumption. Nothing will work if you start with the assumption that it will not work.

51	We typically fill the pile with sand to reduce local buckling risk. Could you comment on this?	I have never tested something like that, but I do not think the sand will prevent buckling.
52	When designing a capacity-protected cap, do we design the reinforced concrete (RC) connection based on the capacity of the RC column?	Yes, that is the reason engineers wanted that connection. They did not want to design to the capacity of the CFST. That connection was developed because engineers requested it.
53	Can you place the CFST into the footer form and cast it with the footer in the monolithic concrete, or is the fiber-reinforced concrete near the tube required?	Yes. We have tested monolithic connections many times. They behave as well or better than grouted connections.
54	Is the shear stress between the concrete and steel lost with shinkage of the concrete?	It can be with a large diameter tube. However, shrinkage depends on loss of moisture during curing, and CFSTs are sealed around the perimeter for the entire length of the tube. This inhibits moisture loss. We have done experiments that show that CFSTs have less shrinkage than RC members of the same size. We like to use low-shrinkage concrete and spirally-welded tubes in that case because these lead to better bond stress transfer. You can also place a rib inside the tube to prevent slip, and that will develop the required bond stress.
55	How many rings are needed to develop for composite behavior in piles?	Just one ring is needed.
56	Do we have to use a special mixture of concrete to ensure shear stress development between the two materials?	We encourage low-shrinkage, self-consolidating concrete because we never vibrate CFSTs during placement. However, a special concrete mix is not required.
57	For underwater offshore structures, corrosion is a significant issue. Sacrificial nodes are used to minimize the corrosion issue.	Yes, sacrificial anodes have been used for underwater structures. Similar techniques have also been used for bridges out of water, employing a small induced current flow in Oregon coastal bridges. Coatings, wraps, and galvanization can also be used.
58	If you have a deep pile, how can the steel tube be monitored and maintained? Is the whole life cost considered? The reason for asking is because a large-scale project with 50 piles requiring deep galvanizing of all tubes can be a very expensive solution.	Corrosion is expected over a limited depth. It is most serious in areas subject to periodic wetting and drying. Hence, I do not think you would galvanize the entire depth. I would also like to dispel the assumption that concrete piles do not corrode. Concrete has no strength and ductility until it has steel. The steel may be covered by a couple of inches of concrete, but moisture can still get in and corrosion can occur.

59	With a moment, does the concrete inside crack and no longer offer resistance as originally expected?	The concrete in a CFST does not crack until the steel yields. You talk about spiral rebar confining concrete, but the tube confines it so much better that the spiral. The concrete cannot do anything except go along with the steel. Once the steel elongates due to yielding deformation, local buckling will start to occur. At this point the concrete is not very well confined, and it starts to crush. This causes deterioration of resistance, not cracking of the concrete, and it occurs at relatively large deformations. We typically do not see local buckling until about 4% drift levels. RC has spalled and exposed the rebar by this deformation. We do not see significant deterioration of resistance until 6% to 8% drift, and RC has fractured rebar by that deformation.
60	Did the steel tube use cold formed or hot rolled steel?	The size tubes we discuss are hot rolled plate or coil steel formed into a tube.
61	Is plastic hinge formation possible in the CFST?	Absolutely. That is the way they perform. If the tube is compact, it develops a plastic hinge and eventually has local buckling after the plastic hinge has gone through significant inelastic deformation.
62	What is the type and grade of steel in the CFST?	Many different grades of steel are used in CFSTs, mostly American Petroleum Institute (API) 5L tubes. There is a wide range of strengths. We use 42 to 70 ksi yields.
63	Would the added strength of the CFST members compared to RC members, when they are used as ductile components, result in larger design forces for capacity-protected elements connected to them? Also, would this increase the costs?	Yes, but you can use a smaller CFST, or you can use a weaker CFST connection as previously described.
64	Are the current AASHTO specifications current with your research?	In general, the AASHTO specifications are current with our research.