TECHNICAL NOTE

Hollow Threaded Rebar for Cross Hole Sonic Logging Access Tubes Combined with Longitudinal Concrete Reinforcing in Drilled Shafts

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ABSTRACT

Crosshole Sonic Logging (CSL) of drilled shafts requires 1.5-in (38-mm) or 2-in (51-mm) I.D. sonic access tubes to be installed inside the steel reinforcement cage. The sonic access tubes do not contribute to the structural capacity of the drilled shaft. The proposed use of *Ischebeck TITAN T73/56 CSL/Hollow Threaded Rebar for Cross Hole Sonic Logging Access Tubes Combined with Longitudinal Concrete Reinforcing in Drilled Shafts (patent pending)* is discussed as an alternative method of construction and CSL probe access. The T73/56 hollow threaded rebar/sonic access tube performs as a high strength rebar while at the same time creating a 2.2-in (56-mm) I.D. sonic access tube. The deformed high strength hollow bar provides better adhesion to concrete thus reducing the problem of debonding associated with smooth PVC and steel pipe. A cost comparison using conventional rebar with added sonic access tubes is discussed. The use of T73/56 CSL/Hollow Threaded Rebar as a value engineering alternative can reduce both material and labor costs for drilled shaft construction and can provide an advantage where anchor bolt cages and longitudinal reinforcing create congestion.

BACKGROUND

Crosshole sonic logging (CSL) is a method to verify the integrity of drilled shafts and other concrete piles as prescribed by *ASTM D6760 – 08, Standard Test Method for Integrity Testing of Concrete Deep Foundations by Ultrasonic Crosshole Testing.* This method is considered to be more accurate than sonic echo testing in the determination of soundness of concrete within the drilled shaft inside of the rebar cage. This method provides little indication of concrete soundness outside the cage.

CSL normally requires steel (preferred) or plastic tubes (PVC) to be installed in the drilled shaft and tied to the rebar cage. Before the rebar cage is placed in the drilled shaft, the plastic or, ideally, steel sonic access tubes are attached to the interior of the rebar cage. Then the cage is lowered into the hole and concrete is placed.

The tubes are filled with water as an intermediate medium. After curing for at least 3-7 days, a sound source and receiver are lowered in separate tubes, maintaining a consistent elevation between source and sensor. A signal generator generates a sonic pulse from the emitter which is recorded by the sensor. Relative energy, waveform and differential time are recorded, and logged. This procedure is repeated at regular intervals throughout the pile by length and by quadrant, and then mapped. By comparing the graphs from the various combinations of access tubes, a qualitative idea of the soundness of the concrete throughout the pile can be gleaned.

Cross Hole Sonic Logging is required by most DOT's (O'Neil and Reese, 1999) and transmission line owners for quality control of drilled shaft construction. Current practice is to add 1.5-in (38-mm) or 2-in (51-mm) I.D. tubes for instrumentation access throughout the length of the drilled shaft. There are typically 3 to 8 CSL access tubes per drilled shaft. A general rule of thumb is one CSL access tube per foot of diameter of the drilled shaft. Each drilled shaft tested using CSL requires these access tubes.

PROBLEM STATEMENT

Traditionally, smooth PVC or steel pipe is used to create the sonic access tubes for the CSL logging test. Probes travel the entire length of the drilled shaft. Reports of debonding of the PVC or smooth steel pipe from the concrete are known to occur, usually in the upper portion of the pile and rarely in the lower portion. Fig. 1 illustrates PVC sonic access tubes added to the rebar cage.

The following is a verbatim extract from specifications for a project where CSL testing is prescribed.

"If CSL probes will not pass through the entire length of the CSL tubes, core a 2 in (51 mm) diameter hole through the concrete the full length of the drilled pier for each inaccessible tube. If the CSL tubes debond from the concrete, core a 2 in (51 mm) diameter hole through the concrete to the depth of the debonding for each debonded tube. Locate core holes approximately 9 in (230 mm) inside the reinforcement as directed by the Engineer. Fill core holes with clean water and cover to keep out debris. No additional payment will be made for coring due to inaccessible or debonded tubes."

Drilled shafts for transmission line construction can also benefit from the use of hollow rebar access tubes especially where tower anchor bolt cages conflict with the longitudinal reinforcing in the drilled shaft.

[FIG. 1] Typical Drilled Shaft Reinforcing Cage with PVC Sonic Access Tubes Added

VALUE ENGINEERING PROPOSAL

The use of CSL inspection by DOT's and the addition of sonic access conduits to the drilled shaft provide an opportunity for Value Engineering (VE) the current configuration and addressing the debonding issue.

The use of CSL/Hollow Threaded Rebar is proposed as a possible solution:

1. The hollow threaded rebar provides a continuous sonic access tube using watertight couplers to create the required length
2. Couplings are watertight with rubber seals to prevent leakage.
3. CSL/Hollow Threaded Rebar are structural high grade steel and can replace or augment the longitudinal reinforcing steel required for axial load design.
4. Less congestion in the rebar cage without additional CSL tubes permits larger windows for concrete to pass through.
5. Deformations on hollow threaded rebar and material stiffness should provide sufficient resistance to debonding from concrete and produce consistent CSL results.

CSL/HOLLOW THREADED REBAR PROPERTIES

TITAN 73/56 CSL/Hollow Threaded Rebar Area = 2.11 in^2; (1360mm^2) which, for rebar substitution, is equivalent to approx 2 each #9 rebar A=2.00 in^2; (1290mm^2).

The hollow threaded rebar has a yield stress f_y of 88.4 ksi (610 MPa) and an ultimate stress f_u of 110.3 ksi (760 MPa). Hollow threaded rebar properties are shown in Table 1.

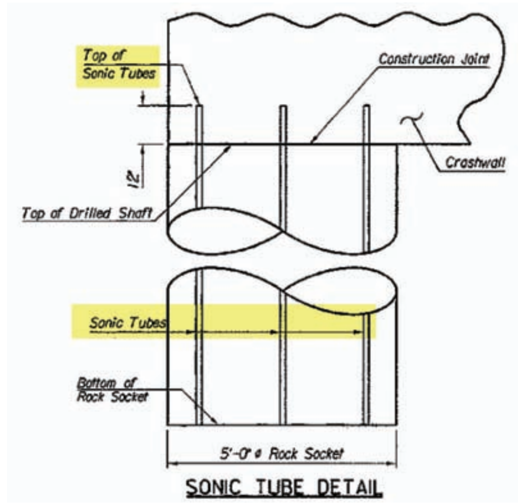
[TABLE 1] CSL/Hollow Threaded Rebar Properties

Rod Size	Area	Load Capasity			Outside Diameter		Weight
D Ø / INNER Ø		Ultimate G.U.T.S	Yield	Max. Test	Effective d Ø	Nominal D Ø	
mm	in^2	kips	kips	kips	in	in	lbs./lf.
	mm^2	kN	kN	kN	mm	mm	kg/m
73/56	2.11	232.7	186.6	185.5	2.76	2.87	7.3
R. H. TREAD	1360	1035	830	825	70	73	10.8

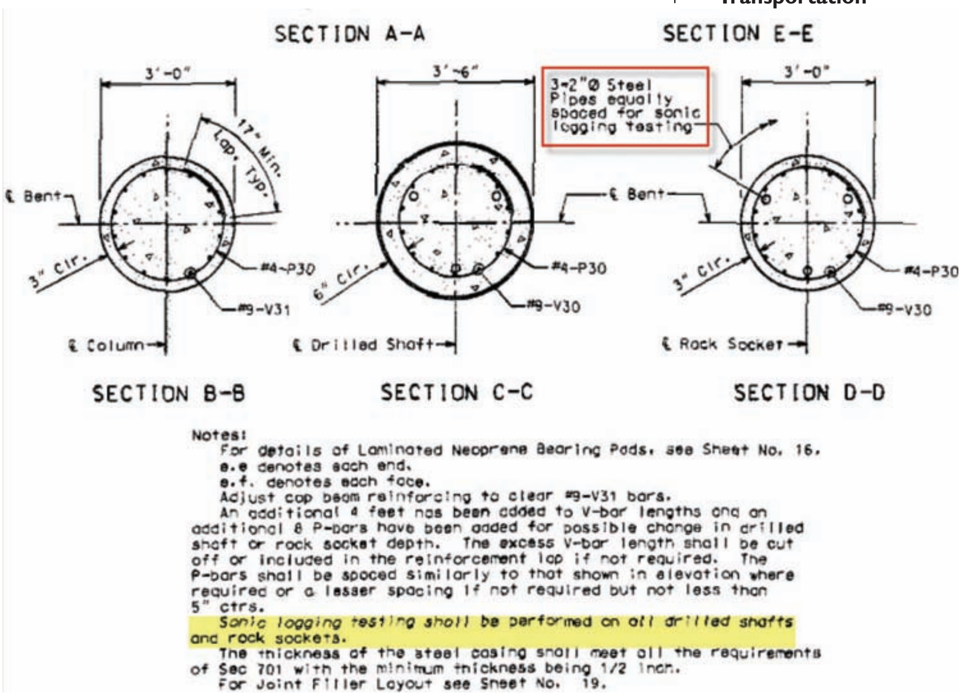
CURRENT DRILLED SHAFT CONFIGURATION

The following discussion illustrates an example current design for a 3’-0” (0.91m) dia. drilled shaft, see Fig. 2. Longitudinal reinforcement consists of 14 each #9 rebar with a total steel area of 14 sq in.; (9032mm^2). Add three each 2 in (51mm) I.D. pipe sonic access tubes for a total of 17 pieces to assemble.

If PVC pipe is used for sonic access tubes, steel mandrels are sometimes used to maintain the position of the tubes during lifting and handling of the rebar cage. Figs. 2, 3 and 4 illustrate current typical CSL design details found on some DOT contract drawings.



[FIG. 3] Sample Detail taken from Kansas Department of Transportation



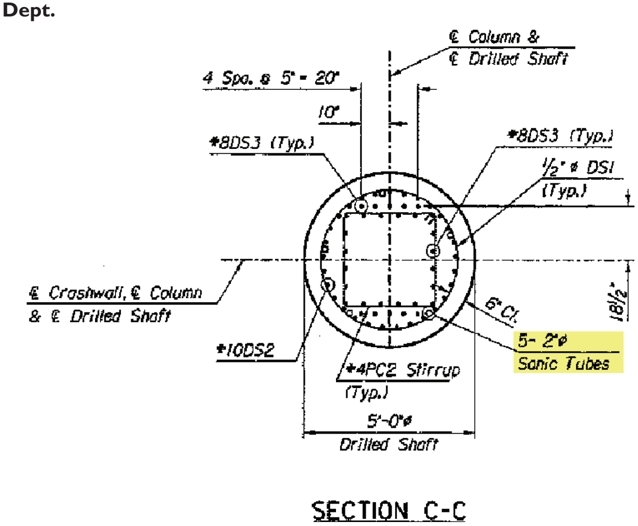
[FIG. 2] Sample Detail taken from Missouri Highways and Transportation Dept.

PROPOSED CONFIGURATION

The following discussion proposes a Value Engineering alternative using CSL/Hollow Threaded Rebar: Use three each CSL/Hollow Threaded Rebar for sonic access tubes and also to replace some of the longitudinal rebar. The CSL/Hollow Threaded Rebar is a structural steel with properties shown under the heading “CSL/ Hollow Threaded Rebar Properties”.

Use eight each #9 (29 mm) rebar between three equally spaced CSL/Hollow Threaded Rebar. Three each hollow bars plus eight each #9 (29 mm) rebar is a total of 11 pieces to assemble compared with the original design which had 17 pieces. Hollow bars can be subsequently filled with cement grout to produce a composite structural section.

The total steel area of conventional reinforcing with 14 each #9 bars is 14 sq. in. (9032 mm^2) steel area for a 3’-0” (914 mm) diameter drilled shaft. Some of these rebar can be replaced by using the structural CSL/Hollow Threaded Rebar. The total bar area is 6.33 sq in. (4084 mm^2) for three CSL/ Hollow Threaded Rebars;

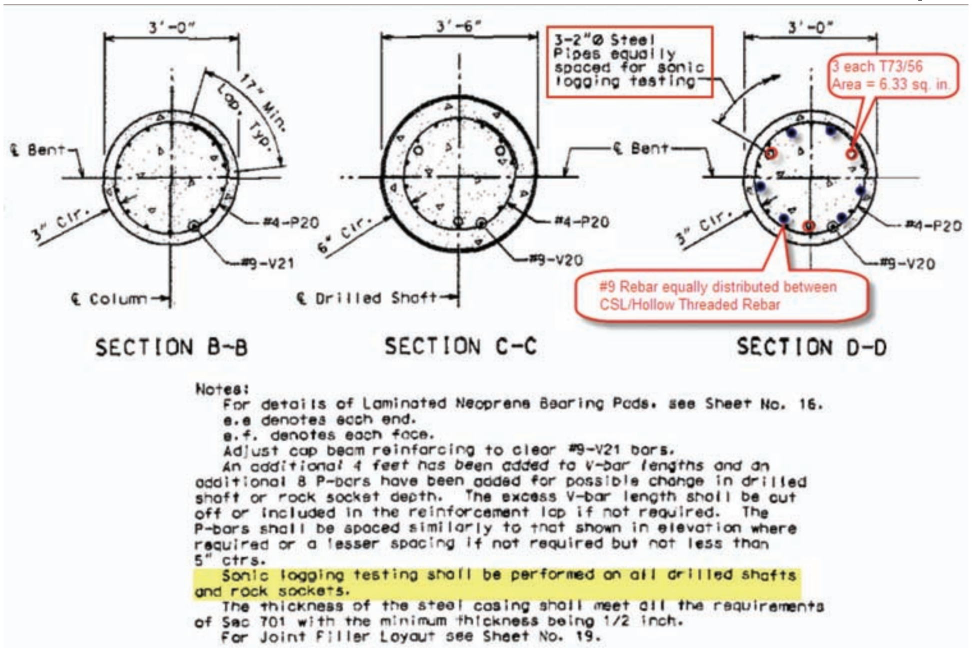


[Fig. 4] Example of Drilled Shaft with 5 each 2” sonic tubes. Sample taken from Kansas Department of Transportation

14 – 6.33 = 7.67 sq in (9032 -4084 = 4948 mm²) steel area required for conventional rebar. Use eight each #9 rebar (A=1.00 sq in or 645 mm²) which is sufficient (8.00 sq in > 7.67 sq in. or in metric terms 5140 mm² > 4948 mm²). Table 2 summarizes the comparison and Fig. 5 shows sections through a drilled shaft using this arrangement of CSL access tubes and conventional rebar.

[TABLE 2] CSL/Hollow Threaded Rebar vs. Conventional Longitudinal Reinforcing

	Conventional		Proposed	
	pieces to assemble	steel area [in²]	pieces to assemble	steel area [in²]
Number of #9 rebar	14	14.00	8	8.00
Number of CSL access tubes	3			
Number of CSL hollow threaded rebar			3	6.33
Totals	17	14.00	11	14.33



[FIG. 5] Sample Detail taken from Missouri Highways and Transportation Dept.

COST CONSIDERATIONS FOR COMPARISON

Comparison should be made on the basis of cost for a complete drilled shaft. All other items being equal, the following is a discussion of costs for the drilled shaft example described under the headings "CSL/Hollow Threaded Rebar Properties" and "Proposed Configuration" above.

Option 1: Three CSL/ Hollow Threaded Rebar as Access Tube and Longitudinal Reinforcing

L= 41'-0" or 12.5 m (stock length 20'-6"or 6.25 m) and eight each #9 (29 mm) rebar L= 40'-0" or 12.2 m

Cost items to consider:

- Labor Cost to install eight each #9 (29 mm) bars
- Material cost of longitudinal reinforcing steel (8 each #9 or 29 mm bars), length= 40 ft (12.2 m)
- Material cost for three each CSL/Hollow Threaded Rebar, length = 41 ft (12.5 m) with waterproof couplings and plastic end caps
- Labor cost to install three each CSL/Hollow Threaded Rebar 73/56 (Bar weighs approx. 7.3 plf or 10.8 kg/m).

Option 2: Conventional Drilled Shaft with 14 each #9 (29 mm) rebar longitudinal reinforcing L= 40'-0" or 12.2 m and three each 2-in (51 mm) steel or PVC pipe sonic access tubes. Overall Length =41'-0"or 12.5 m

Cost items to consider:

- Labor cost to install 14 each #9 (29 mm) bars
- Material cost of longitudinal reinforcing steel (14 each #9 (29 mm) bars) L= 40 ft (12.2 m)
- Material cost of three each 2-in (51 mm) I.D. steel or PVC sonic access tubes L= 41 ft (12.5 m)
- Labor cost to install three each 2-in (51 mm) pipe sonic access tubes

CODE COMPLIANCE

The use of high strength steels with f_y less than 100 ksi (690 MPa) for concrete reinforcing is addressed in the recent Transportation Research Board (TRB) National Cooperative Highway Research Program (NCHRP) Report 679; *"Design of Concrete Structures Using High-Strength Steel Reinforcement"*.

Although the results of this study are favorable and endorse the use of high strength steels with f_y less than 100 ksi (690 MPa), AASHTO has not yet adopted this change.

Also the recommendation to allow high-strength reinforcement is limited to Seismic Zone I. This will limit its use in many areas, including most of the west coast. The ACI code, which governs non-transportation projects, allows f_y up to 80 ksi (550 MPa).

CONFORMANCE WITH ASTM A615 AND A706

Tensile Yield and Ultimate Strength

CSL/Hollow Threaded Rebar has a published yield stress fy of 87 ksi (600 MPa) and ultimate stress fu of 110 ksi (760 MPa). Both figures exceed the minimum tensile requirements of ASTM A615. Preliminary physical testing for compliance with *ASTM A615 / A615M - 09b Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement and ASTM A706 / A706M – 09b Standard Specification for Low-Alloy Steel Deformed Bars for Concrete Reinforcement* indicates the CSL/Hollow Threaded Rebar complies with the requirements of ASTM A615 Grade 60 (420 MPa) and Grade 75 (520 MPa) rebar as well as the ductility requirements of ATM A706.

Elongation

Preliminary tests conducted by Smith–Emery Laboratories, Los Angeles, CA suggest typical elongations of 7% and 8% can be expected. ASTM A615 requires elongation greater than 6% according to the tensile strength requirements in Table 3 for the larger diameters of Grade 75 (520 MPa) equivalent bars. Average elongation of five sample bars recently tested was 7.28% which is greater than the 6% minimum required for Grade 75 rebar (520 MPa).

Bending

Bend Test reports are available which demonstrate the required ductility for 180-degree bending as set forth in ASTM A615 for both full size bars and coupon tests, see Fig. 6.

Chemical Composition

The CSL/Hollow Threaded Rebar complies with ASTM A615 and ASTM A706 for chemical content.

[TABLE 3] ASTM A615 tensile strength and minimum elongation requirements
Note: Metric equivalents bracketed [ ]

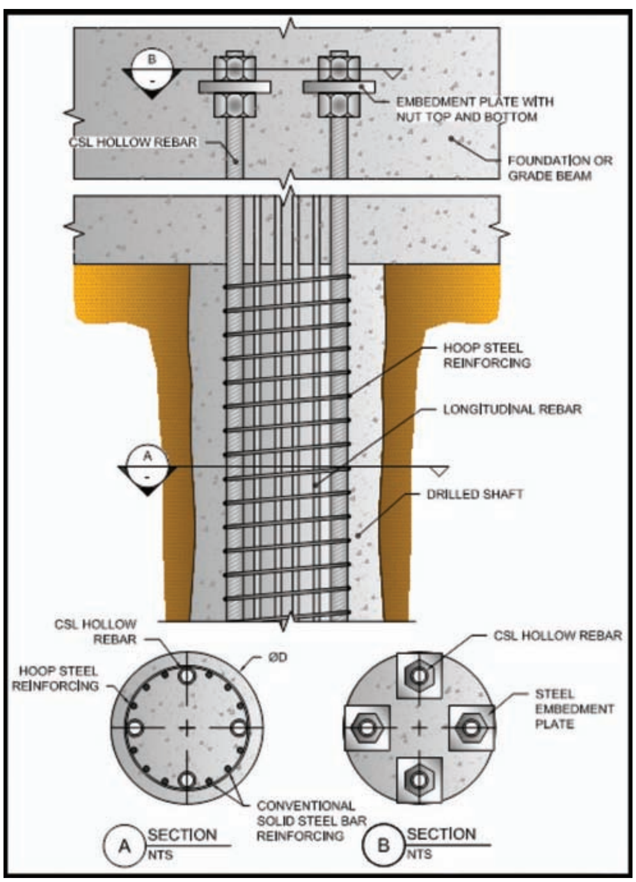
Tensil Requirements			
	Grade 40 [280]^A	Grade 60 [420]	Grade 75 [520]^B
Tensile strength, min, psi [MPa]	60 000 [420]	90 000 [620]	100 000 [690]
Yeild strength, min, psi [MPa]	40 000 [280]	60 000 [420]	75 000 [520]
Elongation in 8 in. [203.2 mm], min, %			
Bar Designation No			
3 [10]	11	9	...
4, 5 [13, 16]	12	9	...
6 [19]	12	9	7
7, 8, [22, 25]	...	8	7
9, 10, 11, [29, 32, 36]	...	7	6
14, 18, [43, 57]	...	7	6

^A Grade 40 [280] bars are furnished only in sizes 3 through 6 [10 through 19].
^B Grade 75 [520] bars are furnished only in sizes 6 through 18 [19 through 57].

Charpy impact Test

Although the Charpy Impact Test is not required by ASTM A615 it does however confirm the steel toughness and ductility. For the normal rotary- percussion drilling of hollow threaded bars, high toughness is required in order to avoid damage and cracks to the hollow bar during the installation process. The steel quality, in accordance with DIN EN 10210, has a toughness of min. 40 Joule for a temperature of -20° C (-40 F).

[FIG. 6] 180° bend test on Hollow Threaded Rebar



[FIG. 7] Typical CSL Hollow Threaded Rebar Detail

CONCLUSION

CSL/Hollow Threaded Rebar for drilled shaft sonic access tubes can also be used as longitudinal reinforcing thereby serving two purposes and reducing labor and material cost for CSL access; see Fig. 7.

A typical CSL/Hollow Threaded Rebar/ sonic access tube has an area of 2.11 sq in (1361 mm^2), approximately equal to 2 each #9 rebar (2.0 sq in or 1290 mm^2).

Advantages:

1. Potential for savings in material consumption and labor assembly
2. Hollow bars are used for both reinforcing and sonic testing
3. Provides opportunity for value engineering of conventional drilled shaft construction and design methods
4. Debonding of sonic access tubes is reduced as hollow bars perform as rigid reinforcing with deformations
5. Permits larger windows in reinforcing for concrete to pass through
6. The Nominal 3 in O.D. (73 mm) hollow threaded rebar is much stiffer than normal rebar thereby facilitating rebar cage handling
7. Steel mandrels, sometimes used to align PVC tubes during cage handling, are eliminated
8. Independent third party testing has confirmed that CSL/Hollow Threaded Rebar conforms to the physical and chemical requirements of ASTM A615 and A706

REFERENCES

1. American Society for Testing and Materials ASTM A615 / A615M - 09b Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement.
2. American Society for Testing and Materials ASTM A706 / A706M – 09b Standard Specification for Low-Alloy Steel Deformed Bars for Concrete Reinforcement.
3. American Society for Testing and Materials ASTM D4428 / D4428M – 07, Standard Test Methods for Crosshole Seismic Testing.
4. American Society for Testing and Materials ASTM D6760 – 08. Standard Test Method

for Integrity Testing of Concrete Deep Foundations by Ultrasonic Crosshole Testing.

5. O'Neil, M. W. and Reese, L. C., Federal Highway Administration (FHWA) (1999), Drilled Shafts: Construction Procedures and Design Methods, FHWA Report No. FHWA-IF-99-025.
6. Smith-Emery Laboratories report of testing: TITAN 73/56 hollow rebar sonic access tube testing per ASTM A615 and A706. Los Angeles, CA, August 19, 2011.
7. TRB's (Transportation Research Board) National Cooperative Highway Research Program (NCHRP) Report 679: Design of Concrete Structures Using High-Strength Steel Reinforcement. 2011
8. Using Crosshole Sonic Logging (CSL) To Test Drilled-Shaft Foundations, Branagan & Associates, Inc. Las Vegas, NV, 2002, Internet: www.branagan.com

Copies of test results for all aforementioned tests are available upon request.