9/23/2008

Vibration Testing of Tube Bank
Test Samples in Laboratory Setting

1. Introduction and Substantiation

Steam generator tube banks are exposed to hot gases in crossflow at high flow velocities. Under such conditions, their vibration potential (flow-induced vibration potential) needs to be properly assessed and the resistance to vibration explicitly determined. If the resistance to vibration was judged inadequate, implementation of anti-vibration measures would be mandatory.

The single most important parameter which defines the resistance of the tube banks to flow-induced vibration is the logarithmic decrement of damping. Its value plays a decisive role in judging the resistance of the tube bank to flow-induced vibration. The vibration testing therefore was designed to obtain representative values for the tested tube samples as described below.

2. Identification of Test Samples

Four test samples were tested, each consisting of a full loop of two parallel tubes supported by three supports along the length. Each test sample had a specific design of tube supports which are known to play a role in the vibration resistance of the tubes.

The first two coil samples tested were those recently designed for the Vchec and the Little Gypsy contracts of superheater and reheater tubes. The third test sample had the tube supports made with the previously used "dog bone type" supports. The last (fourth) tube sample had yet another type of supports designed by the engineers in China. (For more detailed description of the four cases tested see the identification in Tables 1 through 4.)

3. Description of Testing Methodology and Testing Conditions

The tubes were excited by impact using a rubber hammer and the resulting vibration was measured by an accelerometer securely attached to the tube at midspan between supports. The excitation was in the horizontal (lateral) direction and the mounting of the accelerometer was also in the direction of the prevailing horizontal vibratory motion. The tests were performed with the accelerometer located in the "A" and "B" positions, and at each of the positions, results were obtained by exciting the tubes in position A1, A2, A3 and A4, or B1, B2, B3 and B4 (See Figures explaining the positions of the accelerometer and the corresponding locations of excitation).

The signal from the accelerometer (Bruel and Kjaer type 4370) was processed through a vibration analyzer (Bruel and Kjaer type 2515 vibration analyzer). At each accelerometer position, a great number of excitation cases and corresponding vibration response data were obtained which formed the basis for obtaining a representative average value for the logarithmic decrement.

The analyzer was set for a time mode in which the vibratory response was obtained on a scale of acceleration in mg's (thousands of acceleration of gravity) versus time. A sine wave response was typically obtained and the obtained spectrum was saved for subsequent evaluation. The logarithmic decrement of damping δ was obtained using the expression

$$\delta = \frac{1}{n} \ln \frac{z_1}{z_{1+n}}$$

where z_1	=	amplitude of the first peak in mg's
z_{1+n}	=	amplitude of the last peak in mg's
n	=	number of vibratory peaks excluding the first one

The logarithmic decrements of damping obtained were linearly averaged. Typically about 25 values of the logarithmic decrement were obtained for each tested condition and the average was calculated. (In some cases, in which the results were not clear or were distorted, fewer test cases have been used – this is noted in the tables reporting the results.) The obtained results are given in Tables 1 through 4 for the 4 coil tests performed.

4. Principal Results

The average values for the logarithmic decrement of damping obtained for the 4 tested tube coils are as follow (see also Tables 1 through 4)

Case	Average Logrithmic Decrement of Damping, δ
Stringer-supported Primary Superheater Tube with new support details designed for the Vchec and Little Gypsy Contracts (Table 1)	0.0785
Stringer-Supported Reheater Tube with new support details designed for the Vchec and Little Gypsy Contracts (Table 2)	0.1260
Stringer-Supported Reheater Tube with formerly used "Dog Bone" type tube supports (Table 3)	0.0924
Stringer-Supported Reheater Tube with support details designed by FW engineers in China (Table 4)	0.08015

5. Discussion of Results and Evaluation

The vibration tests showed that the tubes exhibited a relatively strong resistance to vibration, as demonstrated by the evaluated logarithmic decrements of damping. The minimum value of $\delta = 0.0785$ was obtained for the new design of the tube supports in the case of the Primary Superheater Tubes. This corresponds to a critical damping ratio of $\xi = \delta/2\pi = 0.0785/2\,\pi = 0.0125$ or 1.25%. This value is quite large and it demonstrates that the resistance of the tubes to flow-induced vibration is considerable. The other three tube support configurations yielded even higher damping values.

The results of the tests will form the basis for designing the tube banks against flow-induced vortex-excited and also fluidelastic type tube vibration and will be utilized in the Design Standards.

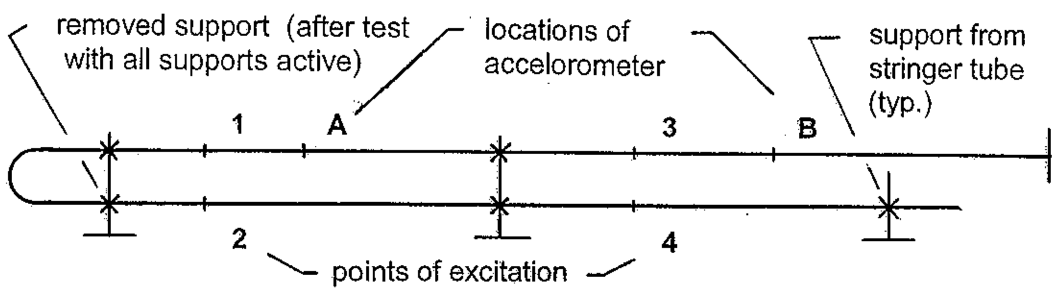
All the numerical results obtained from all the tests are included in the data sheets assembled in the Appendix.

TABLE 1

EVALUATED LOGARITHMIC DECREMENTS OF DAMPING AND VIBRATION FREQUENCIES OF STRINGER SUPPORTED PRIMARY SUPERHEATER TUBE FOR TESTED CONDITIONS OF EXCITATION (NEW SUPPORT DETAILS DESIGNED FOR VCHEC AND LITTLE GYPSY CONTRACTS)

ALL SUPPORTS ACTIVE (SEE DIAGRAM AND NOTATION BELOW)					AFTER ONE SUPPORT REMOVED				
LOADING CONDITION (NO. OF EXCITATION CASES)	LOG. DECREMENT OF DAMPING δ (-)			LOWEST VIBRATION FREQUENCIES f (Hz)	LOADING CONDTION (NO. OF EXCITATION CASES)	LOG. DECREMENT OF DAMPING δ (-)			LOWEST VIBRATION FREQUENCIES f (Hz)
	AVERAGE VALUE	RANGE MAX.	RANGE MIN.			AVERAGE VALUE	RANGE MAX.	RANGE MIN.	
A 1 (25)	.0551	.0214	.973	18, 26	a 1 *	-			
A 2 (25)	.0453	.0052	.0920	16,26	a 2 *	-			
A 3 (25)	.0671	.0226	.1101	12	a 3 (25)	.1654	.0533	.3393	12
A 4 (25)	.1065	.0602	.1542	14, 16, 18	a 4 *	-			
B 1 (25)	.0808	.0055	.1307	12	b 1 (25)	.0564	.0122	.1396	12
B 2 (25)	.0853	.0245	.1794	12,14,16	b 2 (25)	.0755	.0053	.1955	12
B 3 (25)	.0792	.0481	.1381	12	b 3 (25)	.0782	.0070	.1449	12
B 4 (25)	.1088	.0473	.2271	12,16	b 4 *	-			
AVERAGE OF AVERAGE VALUES = .0785					AVERAGE OF AVERAGE VALUES = .0939				

* COIL DID NOT RESPOND WELL TO THIS EXCITATION



Notation :

Loading condition A1 – Accelerometer at location A, tube impacted at location 1

Loading condition a1 – Same as A1 for tube with one support removed

TABLE 2

EVALUATED LOGARITHMIC DECREMENTS OF DAMPING AND VIBRATION FREQUENCIES OF STRINGER SUPPORTED REHEATER TUBE FOR TESTED CONDITIONS OF EXCITATION (NEW SUPPORT DETAILS DESIGNED FOR VCHEC AND LITTLE GYPSY CONTRACTS)

ALL SUPPORTS ACTIVE (SEE DIAGRAM AND NOTATION BELOW TABLE 1)					AFTER ONE SUPPORT REMOVED				
LOADING CONDITION (NO. OF EXCITATION CASES)	LOG. DECREMENT OF DAMPING δ (-)			LOWEST VIBRATION FREQUENCIES f (Hz)	LOADING CONDTION (NO. OF EXCITATION CASES)	LOG. DECREMENT OF DAMPING δ (-)			LOWEST VIBRATION FREQUENCIES f (Hz)
	AVERAGE VALUE	RANGE MAX.	RANGE MIN.			AVERAGE VALUE	RANGE MAX.	RANGE MIN.	
A 1 (25)	.1455	.2268	.0410	12, 18	a 1 (25)	.1011	.1585	.0352	12, 18
A 2 (25)	.2089	.3648	.0216	16,26	a 2 (24)	.1003	.1841	.0408	16, 18
A 3 (25)	.1265	.2389	.0546	12, 14	a 3 (12)	.1617	.3397	.0437	12, 14, 16, 18
A 4 (25)	.1292	.2829	.0199	16, 18	a 4 (11)	.1031	.2226	.0162	18
B 1 (25)	.0769	.1754	.0144	12	b 1 (14)	.1669	.4023	.0355	12
B 2 (6) *	.3003	.4276	.1319	14,16	b 2 (8)	.2078	.4933	.1192	
B 3 (25)	.0691	.1215	.0391	12	b 3 (12)	.0685	.1393	.0242	12
B 4 (4)*	.2181	.2951	.1468	12	b 4 (12)	.1597	.3405	.0649	
AVERAGE OF AVERAGE VALUES = .1260 (EXCLUDING B2 AND B4)					AVERAGE OF AVERAGE VALUES = .1336				

*COIL DID NOT RESPOND WELL TO THIS EXCITATION

TABLE 3

EVALUATED LOGARITHMIC DECREMENTS OF DAMPING AND VIBRATION FREQUENCIES OF STRINGER SUPPORTED REHEATER TUBE FOR TESTED CONDITIONS OF EXCITATION (FORMER "DOGBONE" SUPPORT DETAILS PREVIOUSLY USED FOR CLECO CONTRACT)

ALL SUPPORTS ACTIVE (SEE DIAGRAM AND NOTATION BELOW TABLE 1)				
LOADING CONDITION (NO. OF EXCITATION CASES)	LOG. DECREMENT OF DAMPING δ (-)			LOWEST VIBRATION FREQUENCIES f (Hz)
	AVERAGE VALUE	RANGE MAX.	RANGE MIN.	
A 1 (13)	.0790	.1860	.0396	12
A 2 (12)	.0799	.1453	.0155	
A 3 (15)	.1621	.4180	.0452	
A 4 (10)	.0989	.1728	.0237	
B 1 (25)	.0639	.1884	.0071	12
B 2 (13) *	.1181	.2234	.0493	12
B 3 (25)	.0708	.1296	.0103	12
B 4 (13)*	.1308	.2189	.0514	12
AVERAGE OF AVERAGE VALUES = .0924 (EXCLUDING B2 AND B4)				

*COIL DID NOT RESPOND WELL TO THIS EXCITATION

TABLE 4

EVALUATED LOGARITHMIC DECREMENTS OF DAMPING AND VIBRATION FREQUENCIES OF STRINGER SUPPORTED REHEATER TUBE FOR TESTED CONDITIONS OF EXCITATION
(SUPPORT DETAIL DESIGN BY FOSTER WHEELER ENGINEERS IN CHINA)

ALL SUPPORTS ACTIVE (SEE DIAGRAM AND NOTATION BELOW TABLE 1)				
LOADING CONDITION (NO. OF EXCITATION CASES)	LOG. DECREMENT OF DAMPING δ (-)			LOWEST VIBRATION FREQUENCIES f (Hz)
	AVERAGE VALUE	RANGE MAX.	RANGE MIN.	
A 1 (25)	.0418	.1120	.0089	12, 16
A 2 (24)	.0776	.1947	.0068	12, 16
A 3 (24)	.0889	.2370	.0171	10, 12
A 4 (25)	.1109	.2291	.0266	10, 12, 16
B 1 (25)	.0913	.2315	.0110	10, 12
B 2 (12) *	.0923	.1826	.0126	-
B 3 (25)	.0582	.0939	.0133	10
B 4 (-)*	-			-
AVERAGE OF AVERAGE VALUES = .0801 (EXCLUDING B2 AND B4)				

*COIL DID NOT RESPOND WELL TO THIS EXCITATION

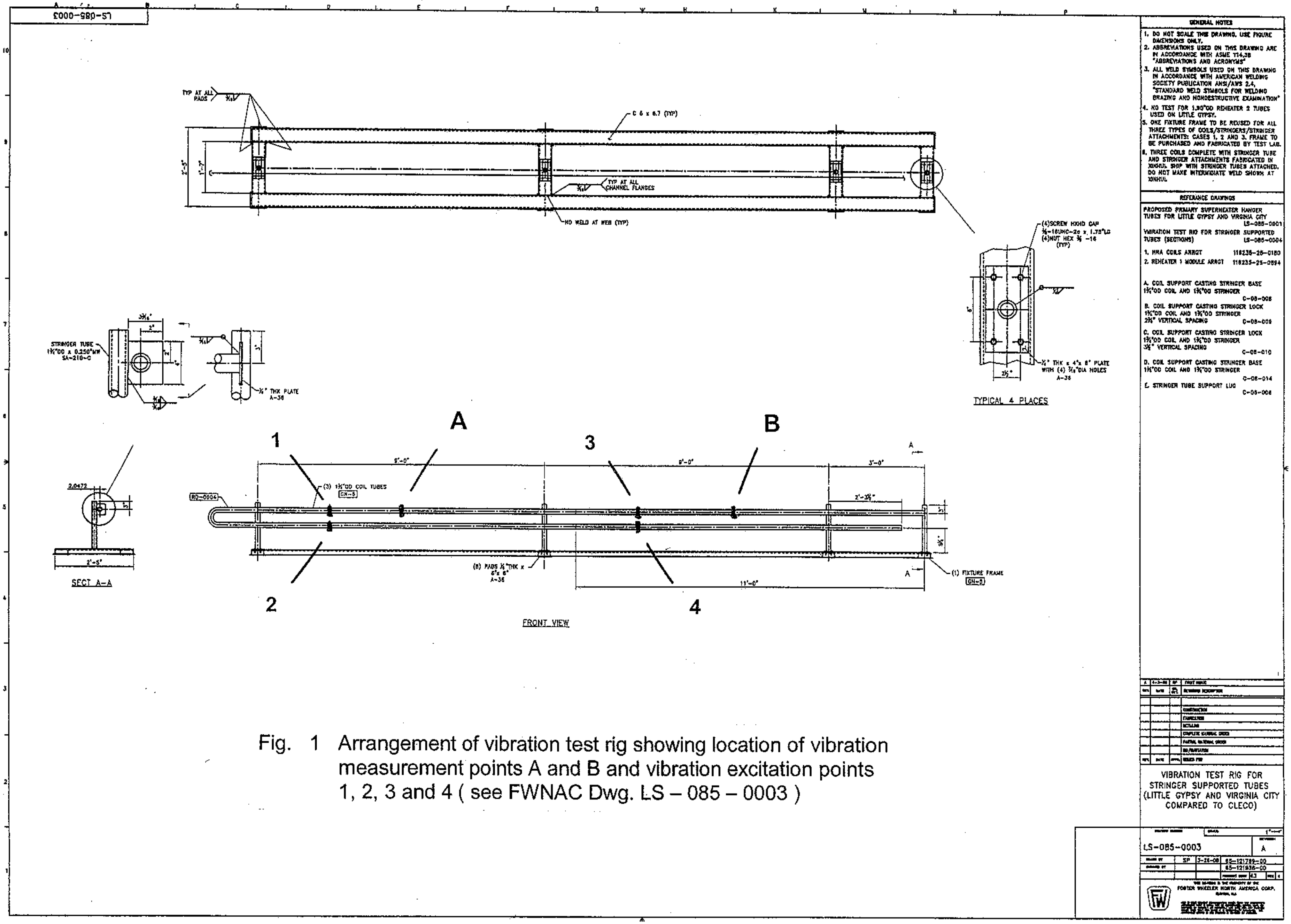


Fig. 1 Arrangement of vibration test rig showing location of vibration measurement points A and B and vibration excitation points 1, 2, 3 and 4 (see FWNAC Dwg. LS – 085 – 0003)

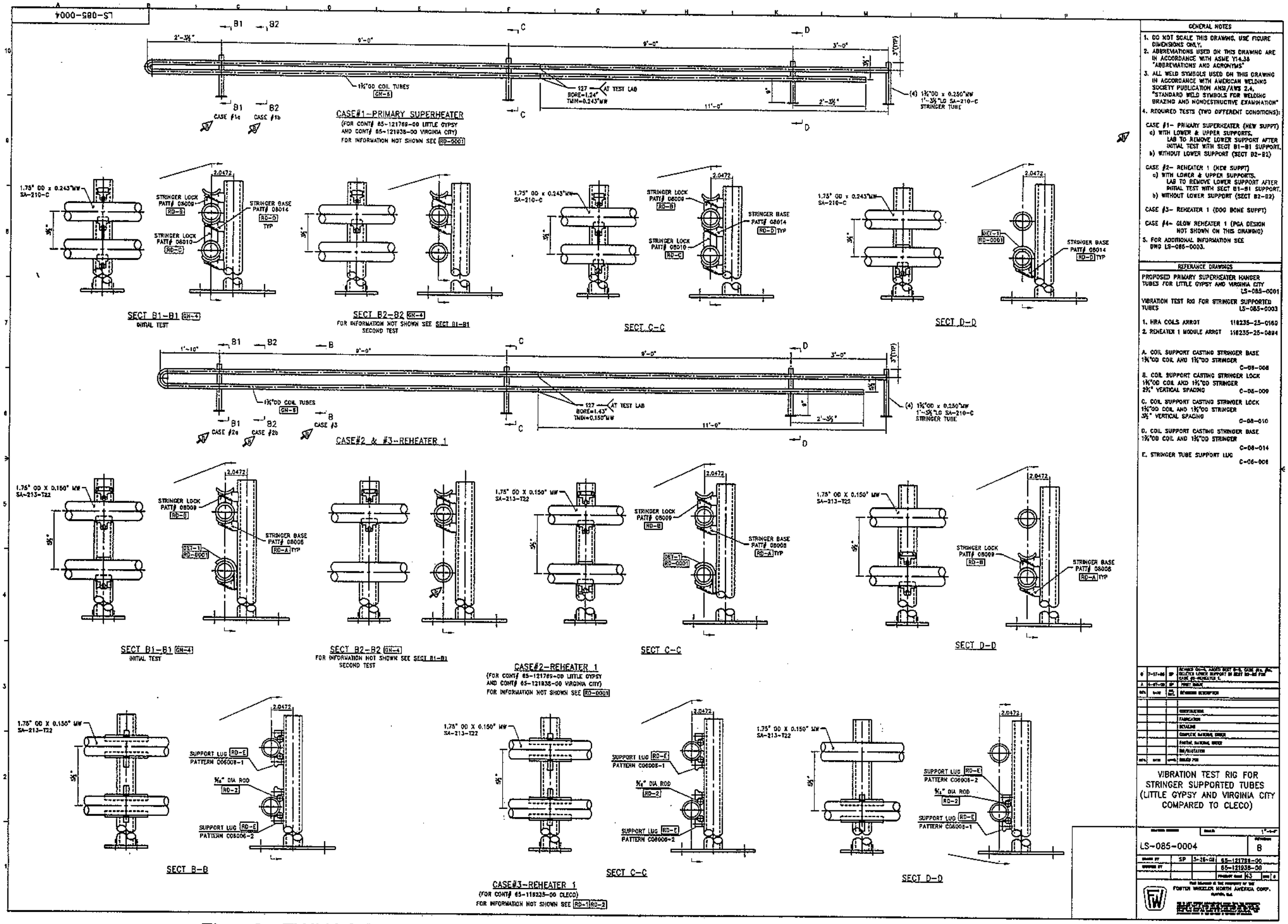


Fig. 2 FWNAC Dwg. LS – 085 – 0004 showing new support details for Primary Superheater tubes and Reheater tubes and former "dogbone" support details for Reheater tubes