

**ENCLOSURE 9**

**WESTINGHOUSE REPORT, WCAP-17548-NP, REVISION 0  
SIGNAL PROCESSING PERFORMED ON MONTICELLO MSL STRAIN GAGE AND  
RSD INSTRUMENTATION DATA**

**58 pages follow**

Westinghouse Non-Proprietary Class 3

WCAP-17548-NP  
Revision 0

May 2012

# **Signal Processing Performed on Monticello MSL Strain Gauge and RSD Instrumentation Data**



**Westinghouse**

**WCAP-17548-NP**  
**Revision 0**

**Signal Processing Performed  
on Monticello MSL Strain Gauge and RSD Instrumentation  
Data**

**AnnMarie Rowland\***  
Acoustic & Structural Analysis

**May 2012**

Reviewer: Inessa E. Berman\*  
Acoustic & Structural Analysis

QA: Tyler W. Crummy\*  
Quality Operations – ES and Major Projects

Approved: David R. Forsyth\*, Manager  
Acoustic & Structural Analysis

\*Electronically approved records are authenticated in the electronic document management system.

---

Westinghouse Electric Company LLC  
1000 Westinghouse Drive  
Cranberry Township, PA 16066, USA

© 2012 Westinghouse Electric Company LLC  
All Rights Reserved

## TABLE OF CONTENTS

LIST OF TABLES .....	iii
LIST OF FIGURES .....	iv
Executive Summary .....	vi
List of Acronyms and Abbreviations .....	vii
Trademark Notes .....	vii
1 BACKGROUND AND INTRODUCTION .....	1-1
1.1 BACKGROUND OF ACOUSTIC ISSUES AND REQUIREMENTS .....	1-1
1.2 REPLACEMENT OF THE STEAM DRYER .....	1-2
1.3 PURPOSE .....	1-3
2 SUMMARY OF PREVIOUS WORK .....	2-1
2.1 ACOUSTIC SCREENING .....	2-1
2.2 SUBSCALE TESTING .....	2-1
2.3 PREVIOUS DATA RECORDINGS .....	2-1
2.4 DERIVATION OF INSTRUMENTATION LOCATIONS .....	2-2
3 DATA COLLECTION AND PROCESSING PLAN .....	3-1
3.1 DATA ACQUISITION AND SIGNAL VALIDITY .....	3-1
3.2 DATA PROCESSING OVERVIEW .....	3-3
3.3 STRAIN TO PRESSURE CONVERSION – MSL STRAIN GAUGE DATA .....	3-4
3.4 NARROW BAND FILTERING .....	3-5
3.5 PSD DERIVATION .....	3-6
3.6 EIC SUBTRACTION .....	3-6
3.7 WAVELET DE-NOISING .....	3-7
4 INPUTS TO SIGNAL PROCESSING AND ASSUMPTIONS .....	4-1
4.1 INPUTS .....	4-1
4.2 ASSUMPTIONS .....	4-1
5 DISCUSSION OF RESULTS .....	5-1
5.1 DATA RECORDING .....	5-1
5.2 STRAIN TO PRESSURE CONVERSION .....	5-4
5.3 FILTERING .....	5-10
5.4 EIC SUBTRACTION WITH DERIVED MSL PRESSURES .....	5-13
5.5 WAVELET DE-NOISING .....	5-15
6 CONCLUSIONS .....	6-1
7 REFERENCES .....	7-1

---

**LIST OF TABLES**

Table 2-1	Natural Frequency of [ ] <sup>b</sup> .....	2-1
Table 2-2	[ ] <sup>a,c</sup> .....	2-3
Table 3-1	[ ] <sup>a,c</sup> .....	3-1
Table 3-2	[ ] <sup>a,c</sup> .....	3-2
Table 3-3	[ ] <sup>a,c</sup> .....	3-2
Table 3-4	[ ] <sup>a,c</sup> .....	3-2
Table 5-1	Transducers and Units.....	5-1
Table 5-2	Dates and Times of Data Recording .....	5-2
Table 5-3	[ ] <sup>a,c</sup> .....	5-4
Table 5-4	[ ] <sup>a,c</sup> .....	5-5
Table 5-5	Summary of Narrow Band Filters.....	5-11

## LIST OF FIGURES

Figure 1-1 Schematic of Replacement Steam Dryer.....	1-2
Figure 2-1 Schematic of MSL [ $J^{a,b,c}$ ].....	2-2
Figure 2-2 Schematic of [ $J^{a,b,c}$ ].....	2-3
Figure 2-3 Schematic of [ $J^{a,b,c}$ ].....	2-4
Figure 2-4 Schematic of [ $J^{a,b,c}$ ].....	2-4
Figure 2-5 Schematic of [ $J^{a,b,c}$ ].....	2-5
Figure 2-6 [ $J^{a,b,c}$ ].....	2-5
Figure 2-7 Schematic of [ $J^{a,b,c}$ ].....	2-6
Figure 3-1 Pipe Mode Diagram, $N=[0,5]$ .....	3-4
Figure 5-1 Examples of Transients in Data.....	5-3
Figure 5-2 MSL [ $J^{b,c}$ ].....	5-6
Figure 5-3 [ $J^{b,c}$ ].....	5-6
Figure 5-4 [ $J^{b,c}$ ].....	5-7
Figure 5-5 [ $J^{b,c}$ ].....	5-8
Figure 5-6 [ $J^{b,c}$ ].....	5-8
Figure 5-7 [ $J^{b,c}$ ].....	5-9
Figure 5-8 [ $J^{b,c}$ ].....	5-12
Figure 5-9 [ $J^{b,c}$ ].....	5-13
Figure 5-10 [ $J^{b,c}$ ].....	5-14
Figure 5-11 [ $J^c$ ].....	5-15
Figure 5-12 [ $J^{a,c}$ ].....	5-16
Figure 5-13 Examples of Cleaned Plant Data Derived MSL Pressures, 100% CLTP .....	5-17
Figure 5-14 Comparison of Raw and Processed Data Derived MSL Pressures, 100% CLTP .....	5-18
Figure 5-15 Attenuation of MSL Data Due to Processing .....	5-19
Figure 5-16 Complete and Final Processed Data Derived MSL Pressures, 100% CLTP .....	5-20
Figure 5-17 [ $J^{b,c}$ ].....	5-21
Figure 5-18 [ $J^{b,c}$ ].....	5-21
Figure 5-19 [ $J^{b,c}$ ].....	5-22
Figure 5-20 [ $J^{b,c}$ ].....	5-23

---

Figure 5-21 [	] <sup>b,c</sup> .....	5-23
Figure 5-22 [	] <sup>b,c</sup> .....	5-24
Figure 5-23 [	] <sup>b,c</sup> .....	5-25
Figure 5-24 [	] <sup>b,c</sup> .....	5-26
Figure 5-25 [	] <sup>b,c</sup> .....	5-26
Figure 5-26 [	] <sup>b,c</sup> .....	5-27
Figure 5-27 [	] <sup>b,c</sup> .....	5-27
Figure 5-28 [	] <sup>b,c</sup> .....	5-29

---

## Executive Summary

Monticello Nuclear generating plant (MNGP, herein referred to as "Monticello") is implementing an extended power uprate (EPU) to increase plant power to [

] <sup>a,c</sup>

[

] <sup>a,c</sup>

[

] <sup>a,c</sup>

[

] <sup>a,c</sup>

[

] <sup>a,c</sup>



---

### List of Acronyms and Abbreviations

AC	alternating current
ACE	acoustic circuit enhanced
BWR	boiling water reactor
CDI	Continuum Dynamics, Inc.
CLTP	current licensed thermal power
DAS	data acquisition system
DS	Downstream (used only in figures and tables)
EIC	electrical interference check
EPU	extended power uprate
GE	General Electric
MNGP	Monticello Nuclear Generating Plant
MSL	main steam line
NRC	Nuclear Regulatory Commission
OEM	original equipment manufacturer
PCF	pressure conversion factor
PSD	power spectral density
RMS	root mean square
RPV	reactor pressure vessel
RRP	reactor recirculation pump
RSD	replacement steam dryer
SIA	Structural Integrity Associates
SNR	signal to noise ratio
SRV	safety relief valve
STFT	short time Fourier transform
SURE	Stein's unbiased risk estimator
US	Upstream (used only in figures and tables)

### Trademark Notes

VersaDAS is a registered trademark of Structural Integrity Associates

# **1 BACKGROUND AND INTRODUCTION**

## **1.1 BACKGROUND OF ACOUSTIC ISSUES AND REQUIREMENTS**

[

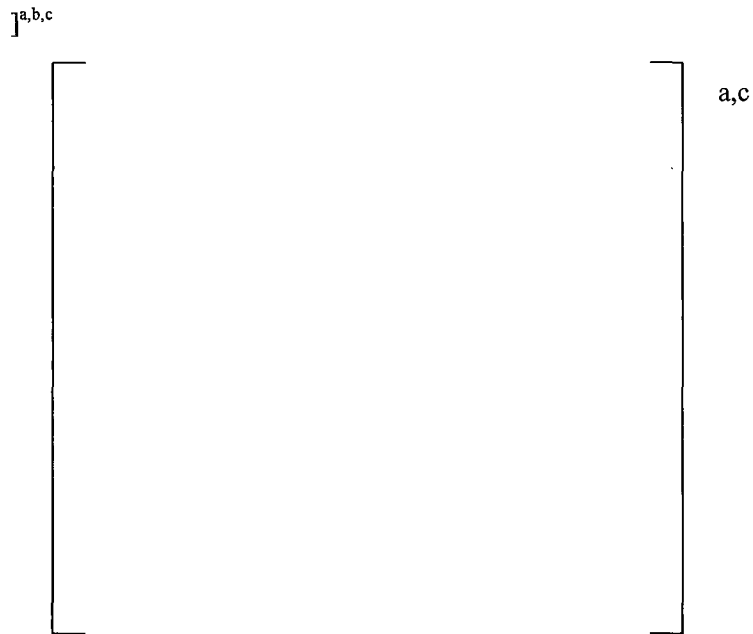
] <sup>a,c</sup>

NRC Regulatory Guide 1.20, Rev. 3 [1], contains requirements for demonstrating the structural integrity of the steam dryer at power levels higher than CLTP. [

] <sup>a,c</sup>

## 1.2 REPLACEMENT OF THE STEAM DRYER

[



**Figure 1-1 Schematic of Replacement Steam Dryer**

[

a,b,c

[

a,b,c

### **1.3 PURPOSE**

This report details the signal processing methods used for processing MSL strain gauge data, and the RSD instrumentation data gathered to support the benchmarking of the Acoustic Circuit Enhanced (ACE) technique used to qualify the steam dryer for acoustic loads at EPU operating conditions. To this end, a summary of the data collection and recorded data at Monticello are contained in this document.

Furthermore, specific datasets are shown and discussed in detail with regard to the signal processing performed. The intention of presenting this data is to demonstrate the effect, and support the use, of the signal processing described herein.

## 2 SUMMARY OF PREVIOUS WORK

### 2.1 ACOUSTIC SCREENING

[

] <sup>a,b,c</sup>

### 2.2 SUBSCALE TESTING

[

] <sup>a,c</sup>

[

] <sup>a,b,c</sup>

Table 2-1 Natural Frequency of [ <sup>b</sup>					
Side Branch	Natural Frequencies				
	Predicted [3]		[ <sup>a,c</sup>		Plant [5]
	Freq., Hz	Difference	Freq., Hz	Difference	Freq., Hz

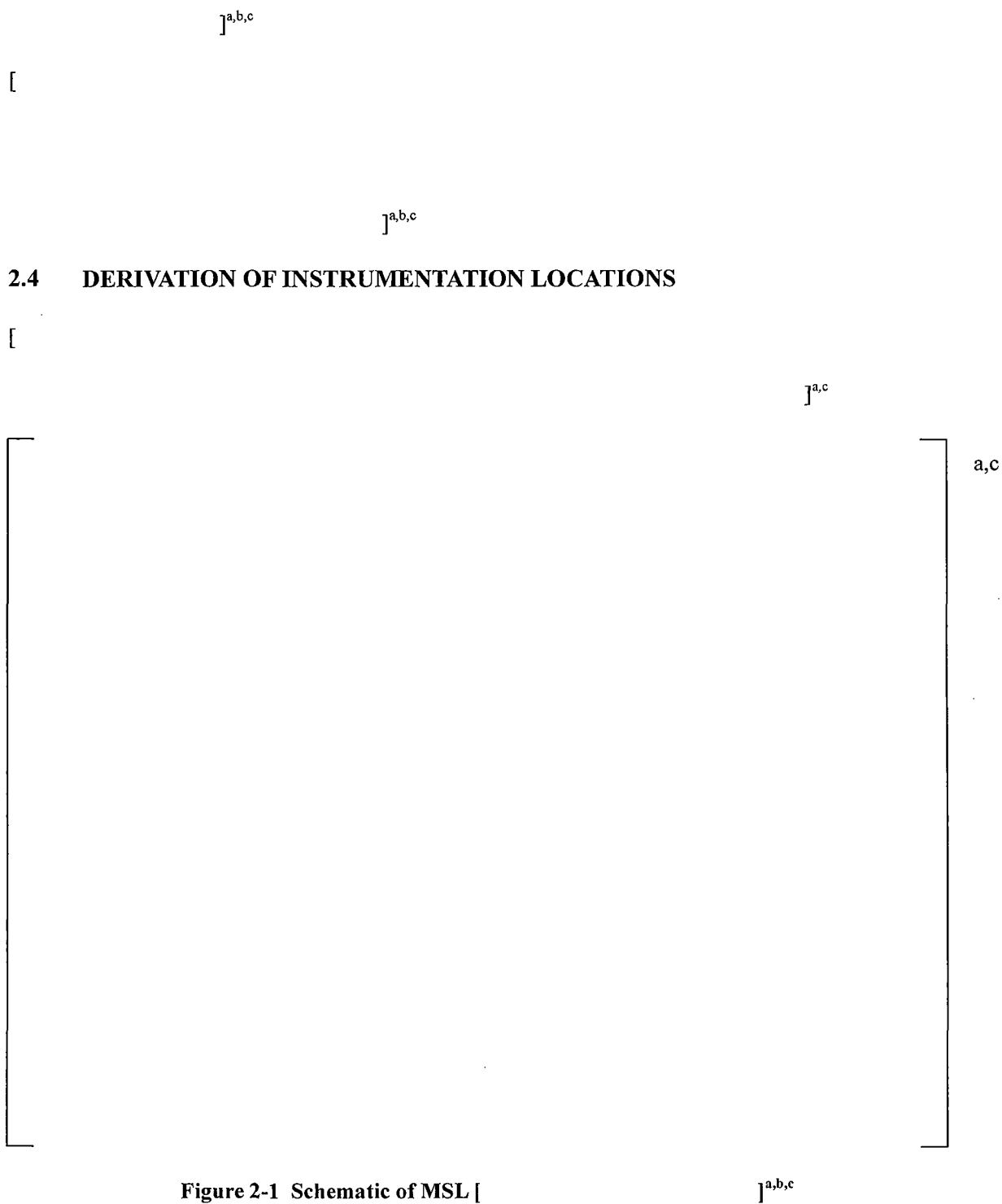
] <sup>b</sup>

### 2.3 PREVIOUS DATA RECORDINGS

[

] <sup>a,c</sup>

[



[

] <sup>a,c</sup>

Table 2-2 [ <sup>a,c</sup>		
MSL	Location	Position

] <sup>a,b,c</sup>

[

] <sup>a,c</sup>

[

] <sup>a,c</sup>

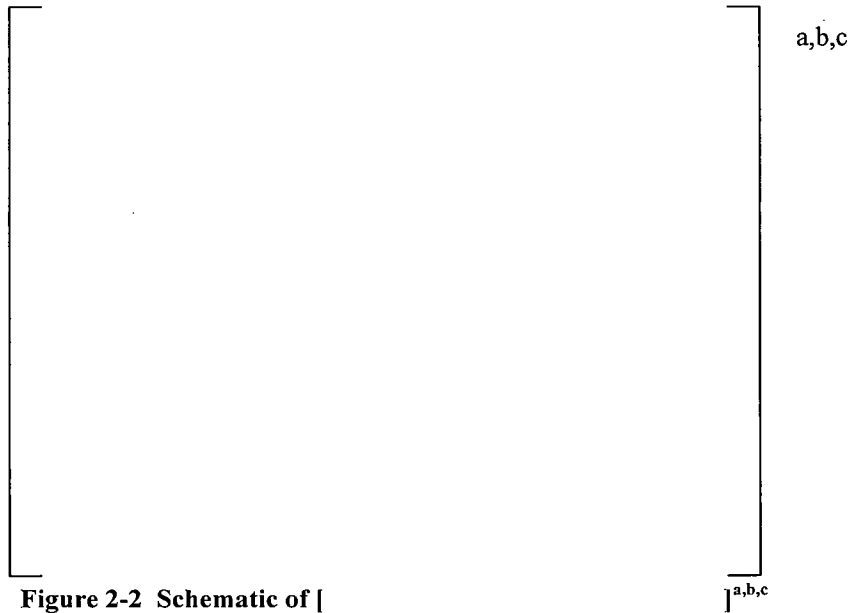
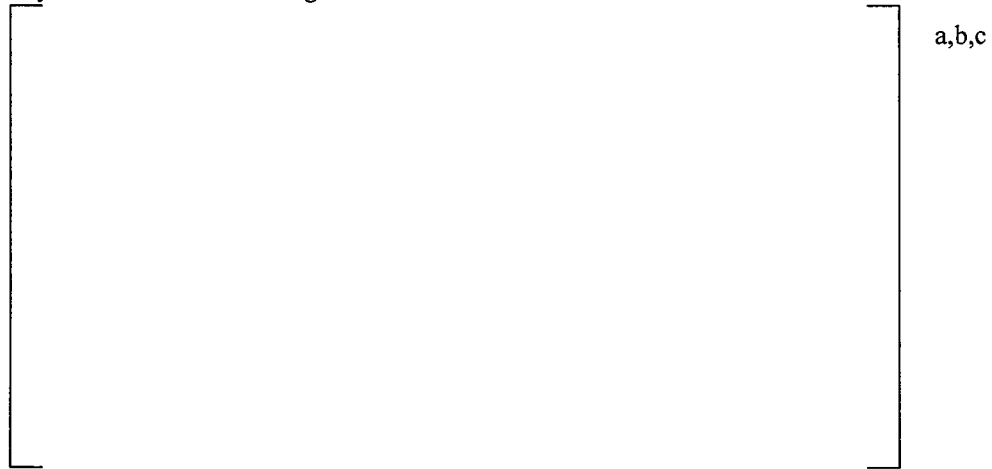


Figure 2-2 Schematic of [

Figure 2-3 through Figure 2-5 show schematic views of the RSD with the strain gauge locations indicated. The view angle is looking slightly down from above and outside the dryer, similar to the view in the overall dryer schematic seen in Figure 1-1.



**Figure 2-3 Schematic of [**



**Figure 2-4 Schematic of [**



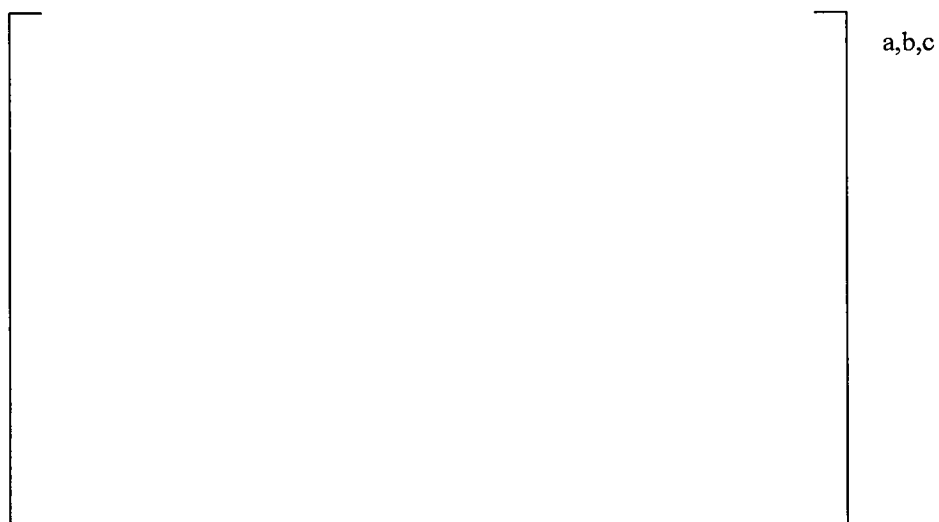


Figure 2-5 Schematic of [

] <sup>a,b,c</sup>

[

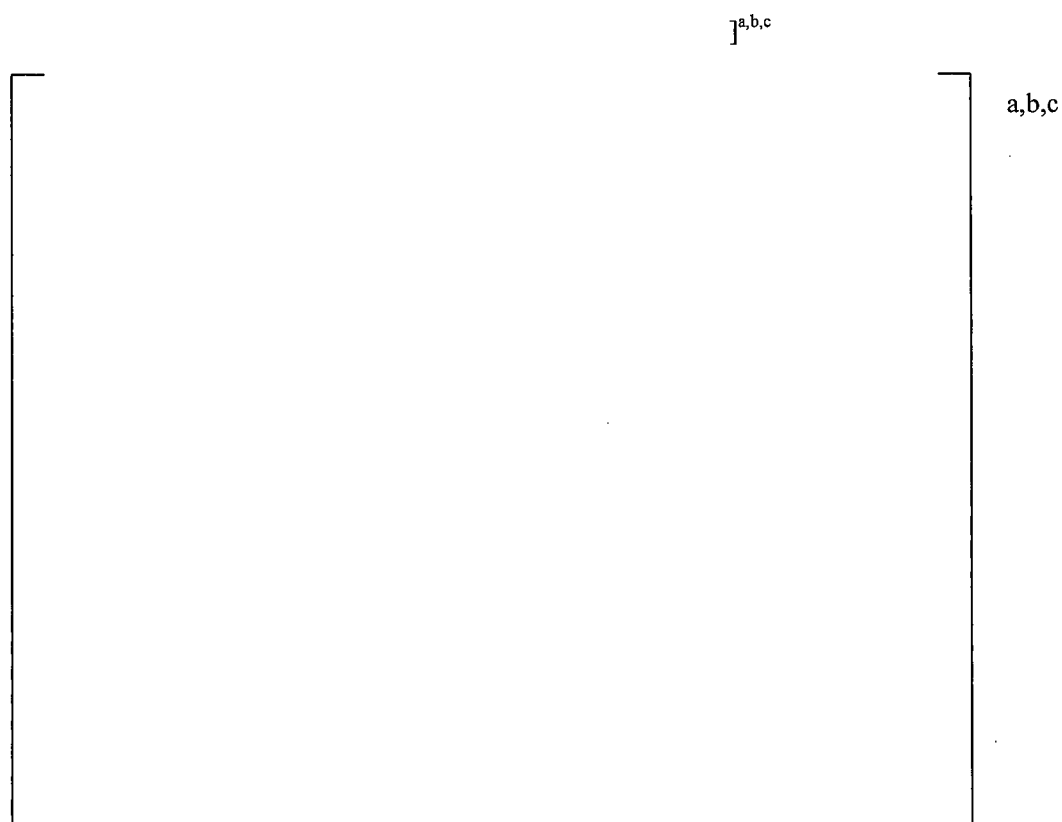
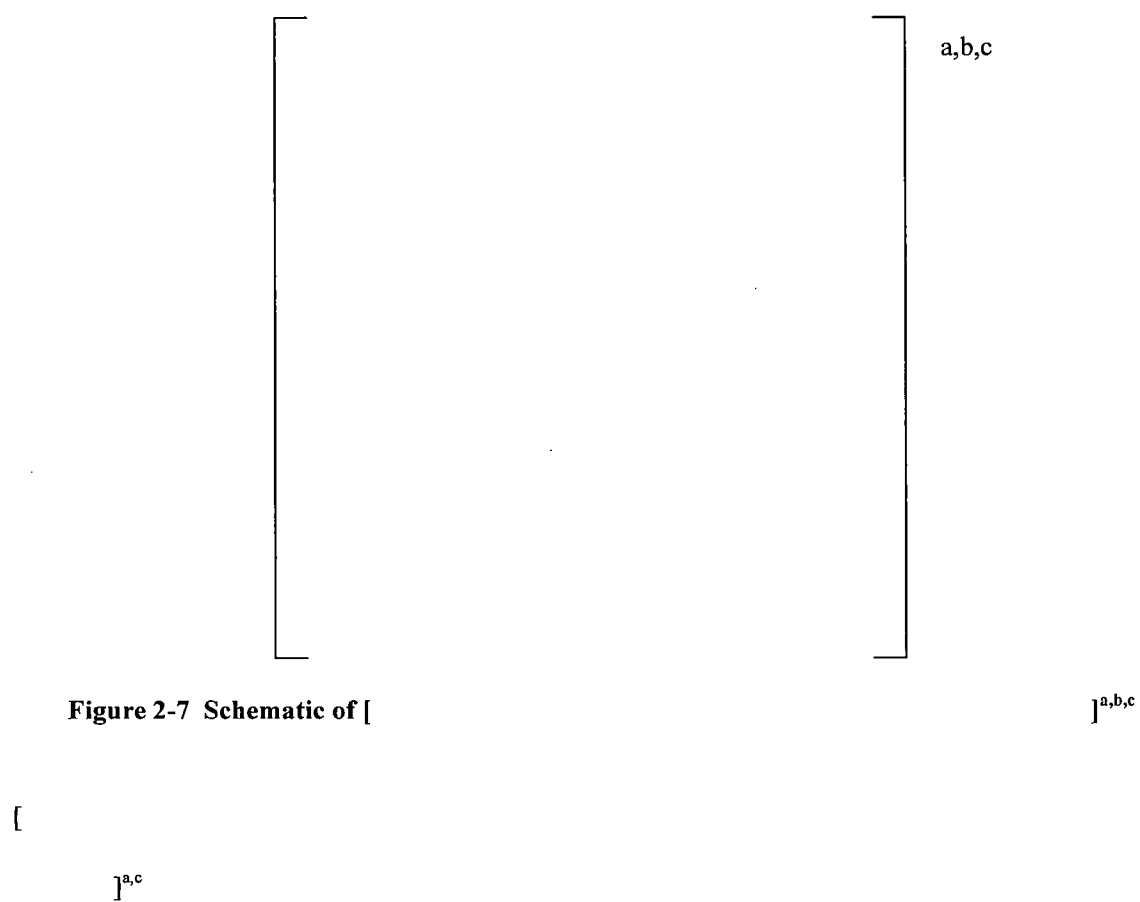


Figure 2-6 [

] <sup>a,b,c</sup>



### 3 DATA COLLECTION AND PROCESSING PLAN

The following sections detail the data collection and processing performed on the recorded time histories from Monticello. The processing documented in this report was applied to the full range of Monticello data in [5] and [8].

#### 3.1 DATA ACQUISITION AND SIGNAL VALIDITY

[

] <sup>a,c</sup>

[

] <sup>a,c</sup>

Table 3-1									

[ ]<sup>a,c</sup>

Table 3-2 [ ] <sup>a,c</sup>				

[ ]<sup>a,c</sup>

Table 3-3 [ ] <sup>a,c</sup>				

[ ]<sup>a,c</sup>

Table 3-4 [ ] <sup>a,c</sup>	

---

[

] <sup>a,b,c</sup>

[

] <sup>a,b,c</sup>

## 3.2 DATA PROCESSING OVERVIEW

[

] <sup>a,b,c</sup>

### 3.3 STRAIN TO PRESSURE CONVERSION – MSL STRAIN GAUGE DATA

[

$$\begin{bmatrix} \vdots \\ \vdots \\ \vdots \end{bmatrix}^{a,c} = \begin{bmatrix} \vdots \\ \vdots \\ \vdots \end{bmatrix}^{a,c} \quad (3-1)$$

where,

$$\begin{bmatrix} \vdots \\ \vdots \\ \vdots \end{bmatrix}^{a,c} = \begin{bmatrix} \vdots \\ \vdots \\ \vdots \end{bmatrix}^{a,c} \begin{bmatrix} \vdots \\ \vdots \\ \vdots \end{bmatrix}^{a,c}$$

**Figure 3-1 Pipe Mode Diagram, N=[0,5]**

[

$\gamma^{a,c}$

$$\left[ \begin{array}{c} \gamma^{a,c} \\ \gamma^{a,c} \\ \gamma^{a,c} \end{array} \right]_{a,c} \quad (3-2)$$

where,

$$\left[ \begin{array}{c} \gamma^{a,c} \\ \gamma^{a,c} \\ \gamma^{a,c} \end{array} \right]_{a,c}$$

$$\left[ \begin{array}{c} \gamma^{a,c} \end{array} \right]$$

### 3.4 NARROW BAND FILTERING

$$\left[ \begin{array}{c} \gamma^{a,c} \end{array} \right]$$

$\gamma^{a,c}$

### 3.5 PSD DERIVATION

The PSDs used in the methods presented in this report were derived using Welch's modified periodogram method. The signal was divided up into time ensembles with the same number of lines as the sampling frequency, resulting in a 1-Hz frequency resolution in the final PSD. A Hanning window was used to reduce spectral leakage, and 50 percent overlap was used in order to increase the number of ensembles available for averaging.

### 3.6 EIC SUBTRACTION

[

[

[

]

a,c

]

]

(3-3)

where,

[

[

]

]

[

]

[

]

(3-4)

where,

[

[

[

]

]

]



The PSDs were derived using Welch's Modified Periodogram method, as described in Section 3.5 [

]<sup>a,c</sup>

### 3.7 WAVELET DE-NOISING

[

]<sup>a,c</sup>

[

]<sup>a,c</sup>

[

]<sup>a,c</sup>

[

]<sup>c</sup>

1. [

]<sup>c</sup>

2. [

]<sup>c</sup>

3. [

]<sup>c</sup>

[

]<sup>c</sup>

[

]<sup>c</sup>

[

]<sup>c</sup>

## 4 INPUTS TO SIGNAL PROCESSING AND ASSUMPTIONS

### 4.1 INPUTS

[

$]^{a,c}$

[

$]^{a,c}$

### 4.2 ASSUMPTIONS

[

$]^c$

[

$]^c$

The acoustic speed in steam is assumed to be 1600 ft/s [12].

[

$]^{a,c}$

[

$]^{a,c}$

[

$]^{a,c}$

[

$]^{a,c}$

## 5 DISCUSSION OF RESULTS

### 5.1 DATA RECORDING

[

] <sup>a,c</sup>

Table 5-1 Transducers and Units	
Transducer	Units

a,c

[

] <sup>a,c</sup>

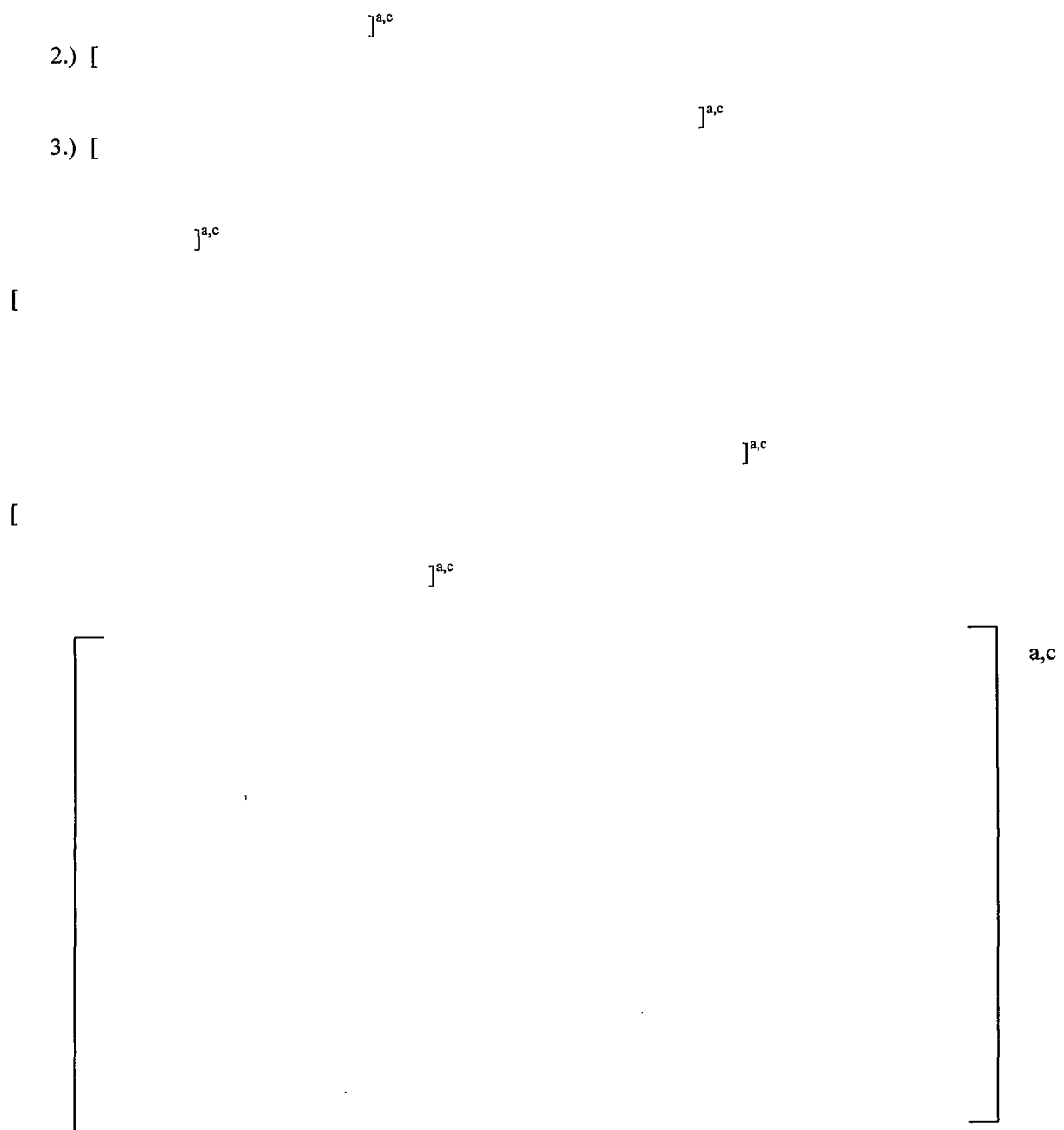
[

] <sup>a,b,c</sup>

---

[

1.) [



**Figure 5-1 Examples of Transients in Data**

[

] <sup>a,b,c</sup>

[

] <sup>a,b,c</sup>

## 5.2 STRAIN TO PRESSURE CONVERSION

[

] <sup>a,c</sup>

[

] <sup>a,c</sup>

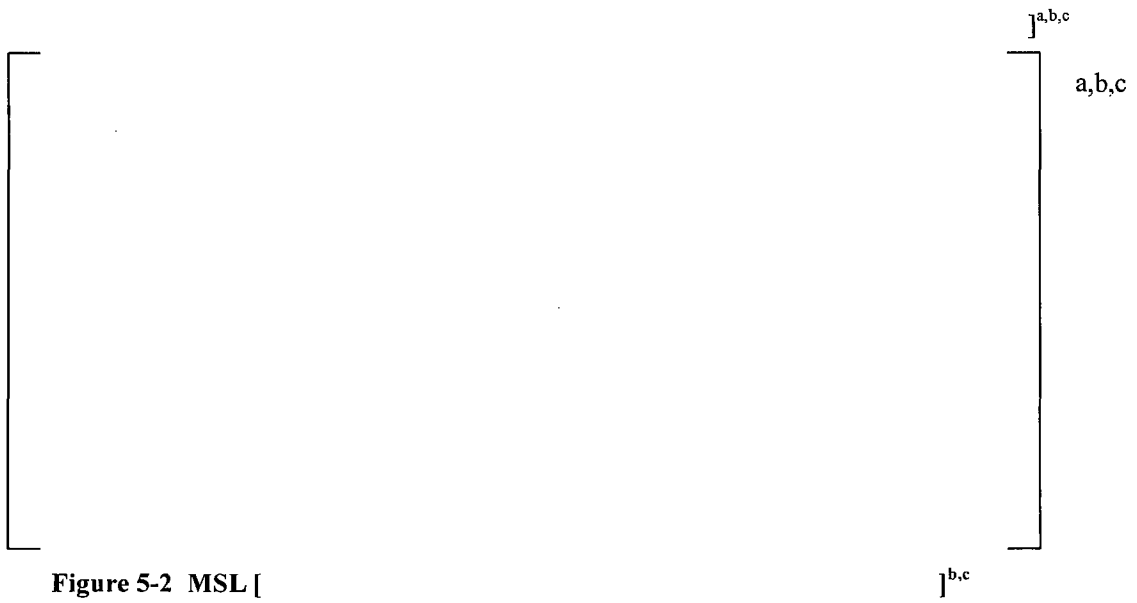
Table 5-3 [ ] <sup>a,c</sup>						
MSL	LOC	Channel				Mean
		1	2	3	4	

b





[



[



[

] <sup>a,b,c</sup>

[

] <sup>a,b,c</sup>

[

] <sup>a,b,c</sup>

[

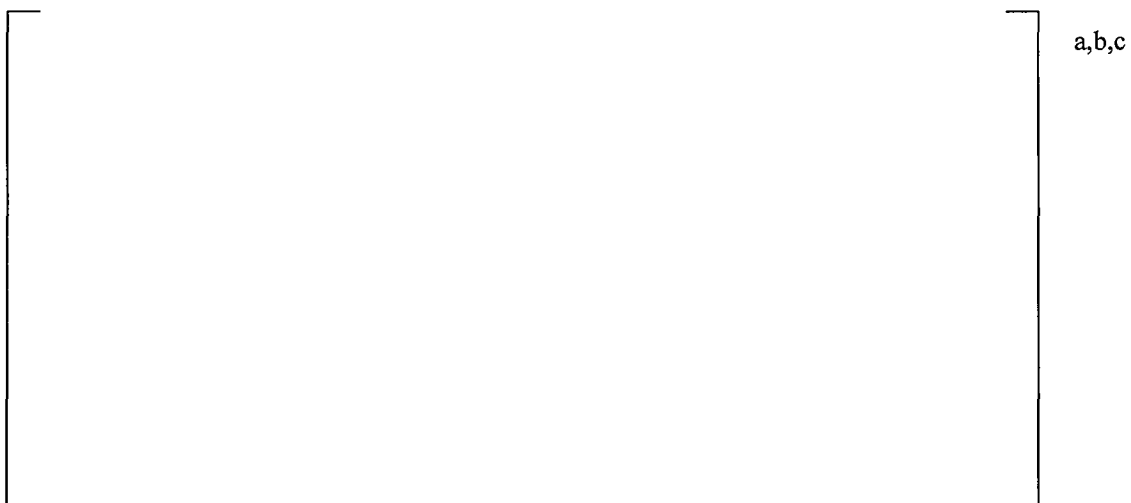
] <sup>a,b,c</sup>**Figure 5-4** [] <sup>b,c</sup>

[

] <sup>a,b,c</sup>

[

] <sup>a,b,c</sup>



**Figure 5-5** [

] <sup>b,c</sup>



**Figure 5-6** [

] <sup>b,c</sup>

[ ] <sup>a,b,c</sup>



[

]a,b,c

---

### 5.3 FILTERING

[

] <sup>a,c</sup>

**Table 5-5      Summary of Narrow Band Filters**

[illegible]
$$\left. \vphantom{\int} \right]^{a,b,c}$$



**Figure 5-8** [

] <sup>b,c</sup>

[

] <sup>a,b,c</sup>

## 5.4 EIC SUBTRACTION WITH DERIVED MSL PRESSURES

[

 $\int^{a,b,c}$ 

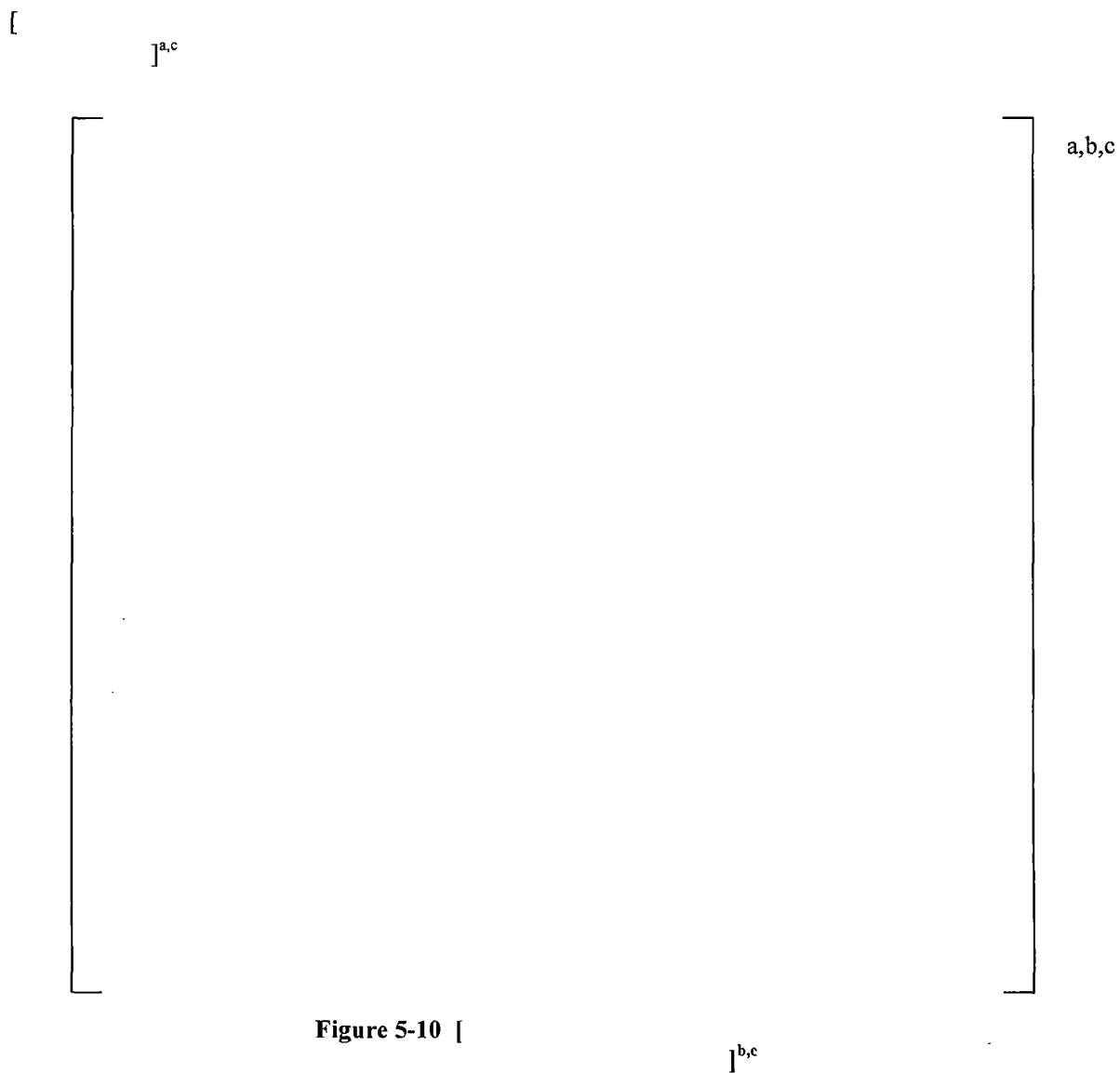
Figure 5-9 [

 $\int^{b,c}$ 

[

 $\int^{a,b,c}$





## 5.5 WAVELET DE-NOISING

$$\begin{bmatrix} \vdots \\ \vdots \\ \vdots \end{bmatrix} = \begin{bmatrix} \vdots \\ \vdots \\ \vdots \end{bmatrix}^{a,b,c} \quad (5-1)$$

Figure 5-11 [

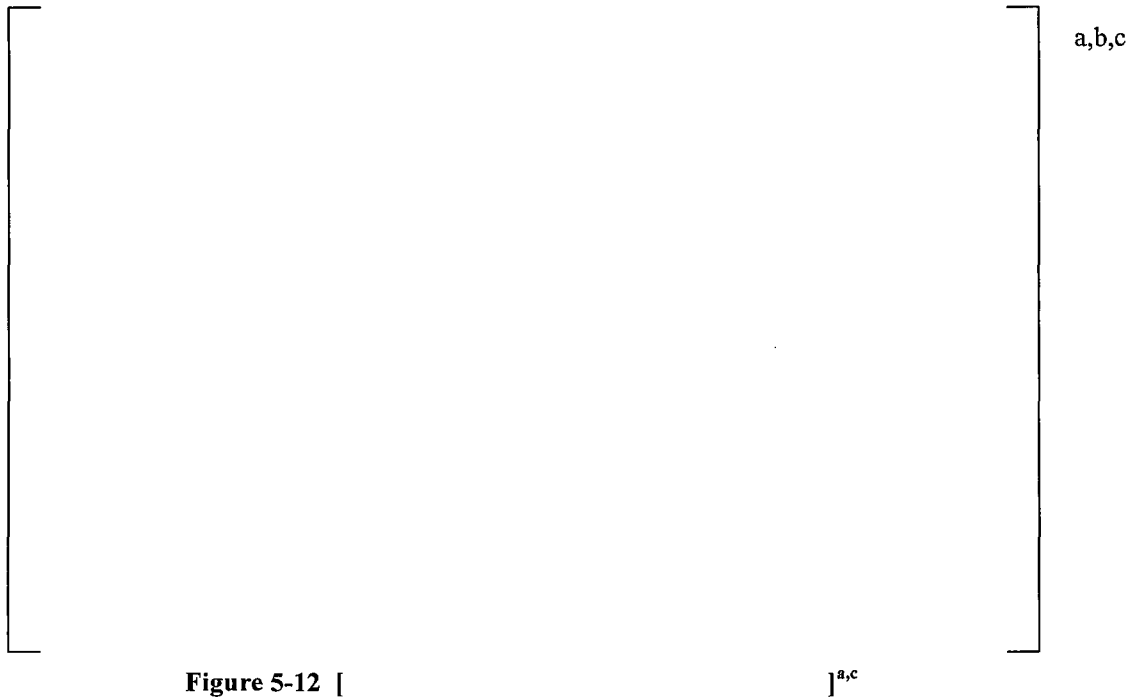
] <sup>c</sup>

$$\begin{bmatrix} \vdots \\ \vdots \\ \vdots \end{bmatrix} = \begin{bmatrix} \vdots \\ \vdots \\ \vdots \end{bmatrix}^{a,b,c}$$

$$\begin{bmatrix} \vdots \\ \vdots \\ \vdots \end{bmatrix} = \begin{bmatrix} \vdots \\ \vdots \\ \vdots \end{bmatrix}^{a,b,c} \quad (5-1)$$

where,

$$\begin{bmatrix} \vdots \\ \vdots \\ \vdots \end{bmatrix} = \begin{bmatrix} \vdots \\ \vdots \\ \vdots \end{bmatrix}^{a,b,c} \quad (5-1)$$

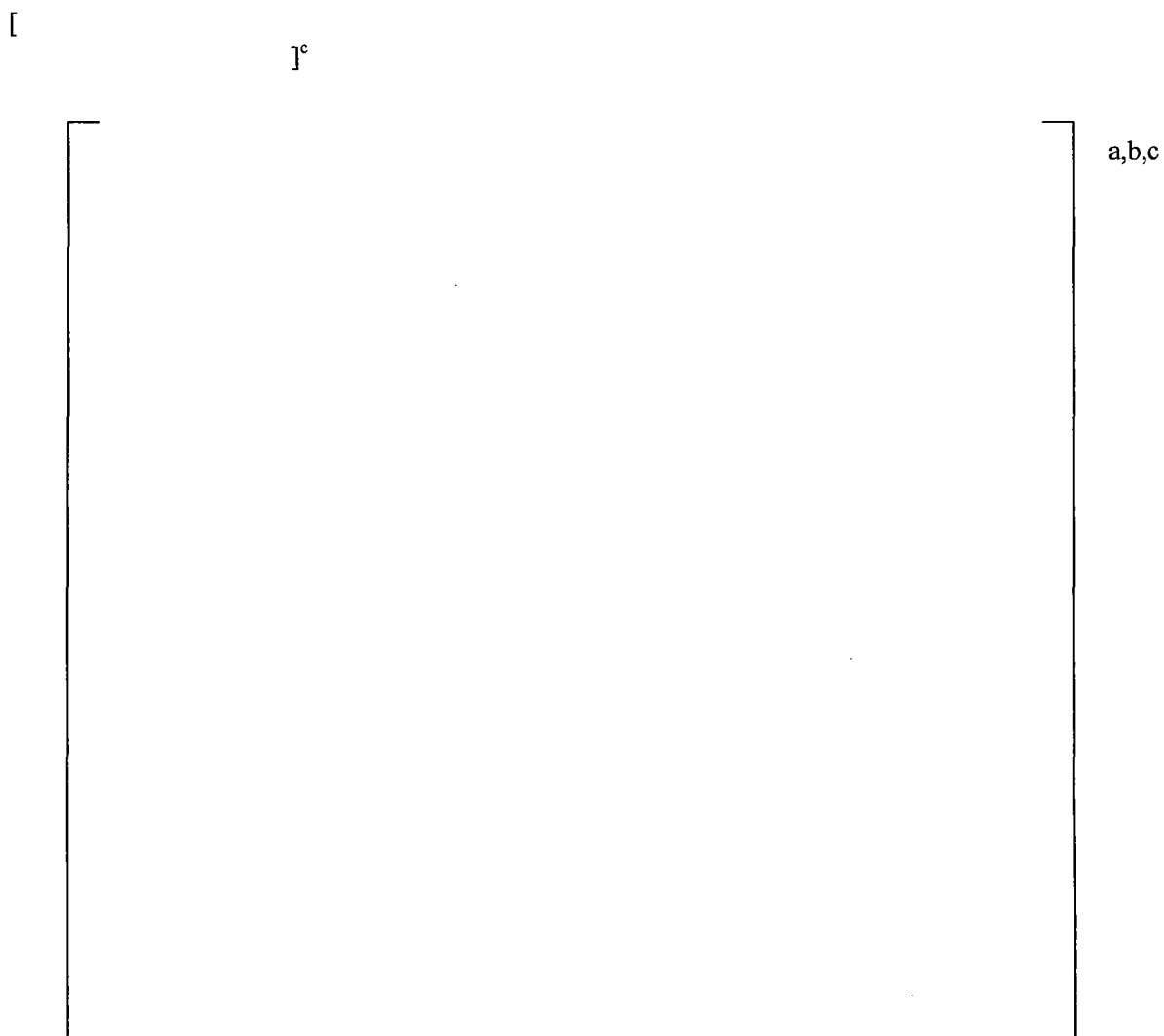


[

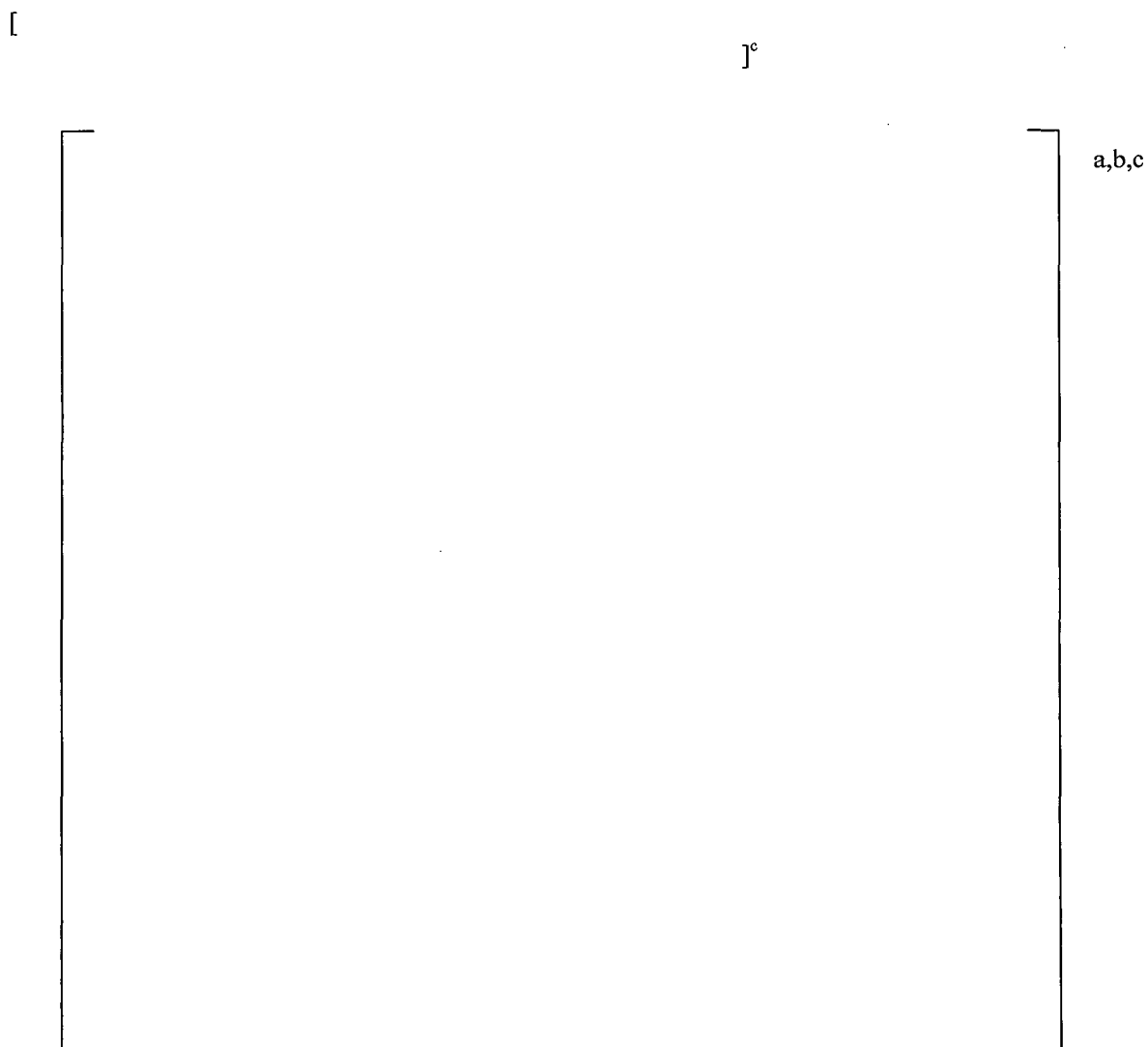
] <sup>a,b,c</sup>

[

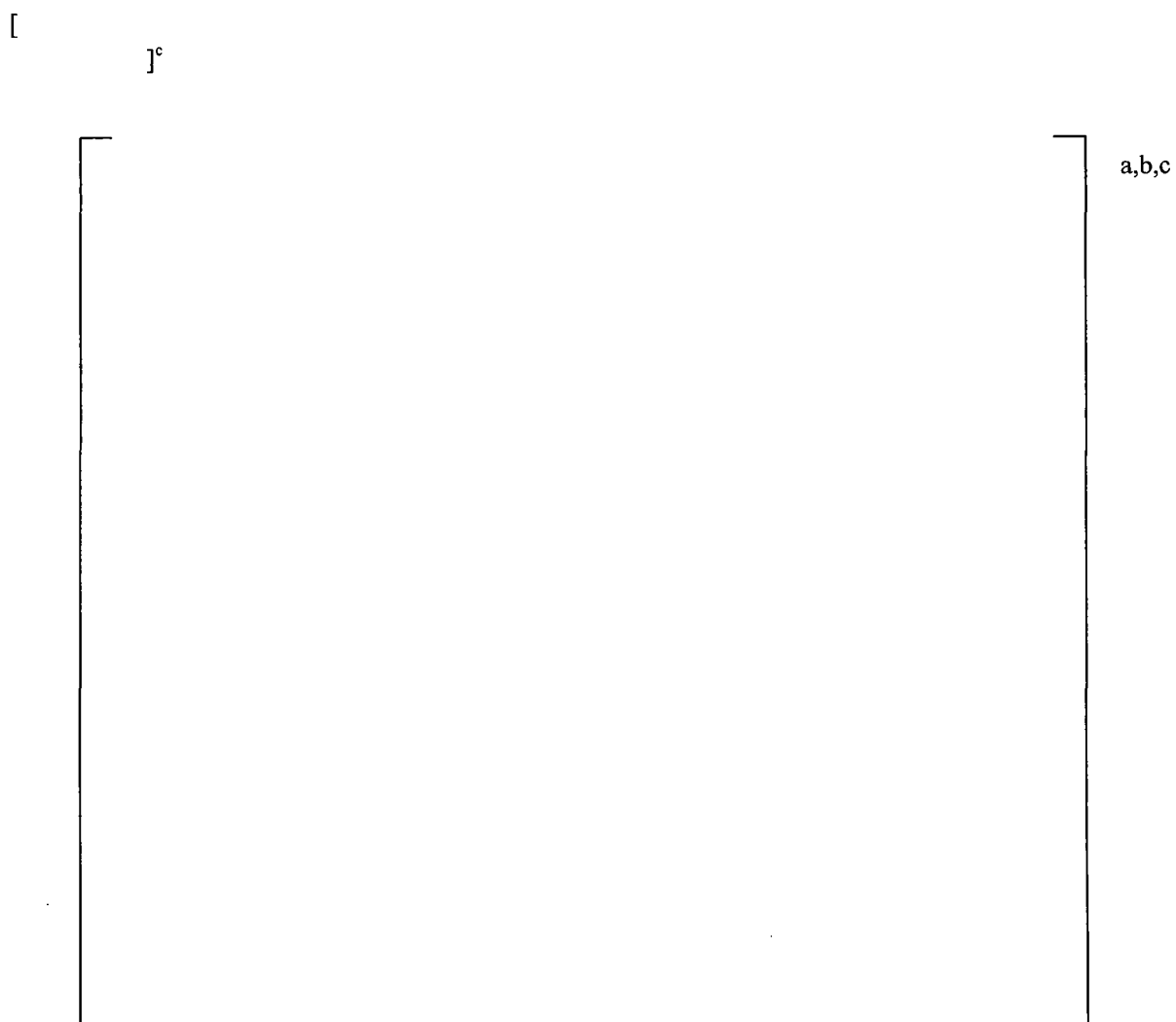
] <sup>a,b,c</sup>



**Figure 5-13 Examples of Cleaned Plant Data  
Derived MSL Pressures, 100% CLTP**



**Figure 5-14 Comparison of Raw and Processed Data  
Derived MSL Pressures, 100% CLTP**

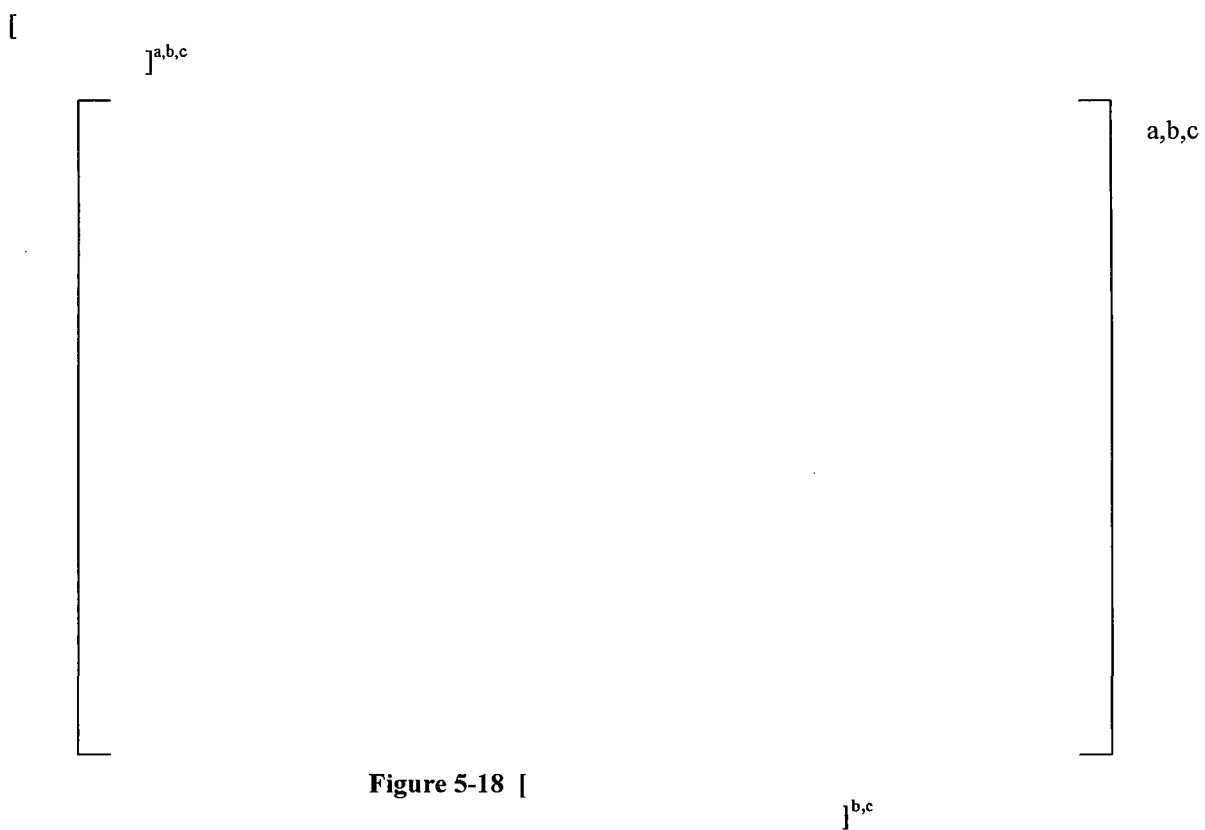
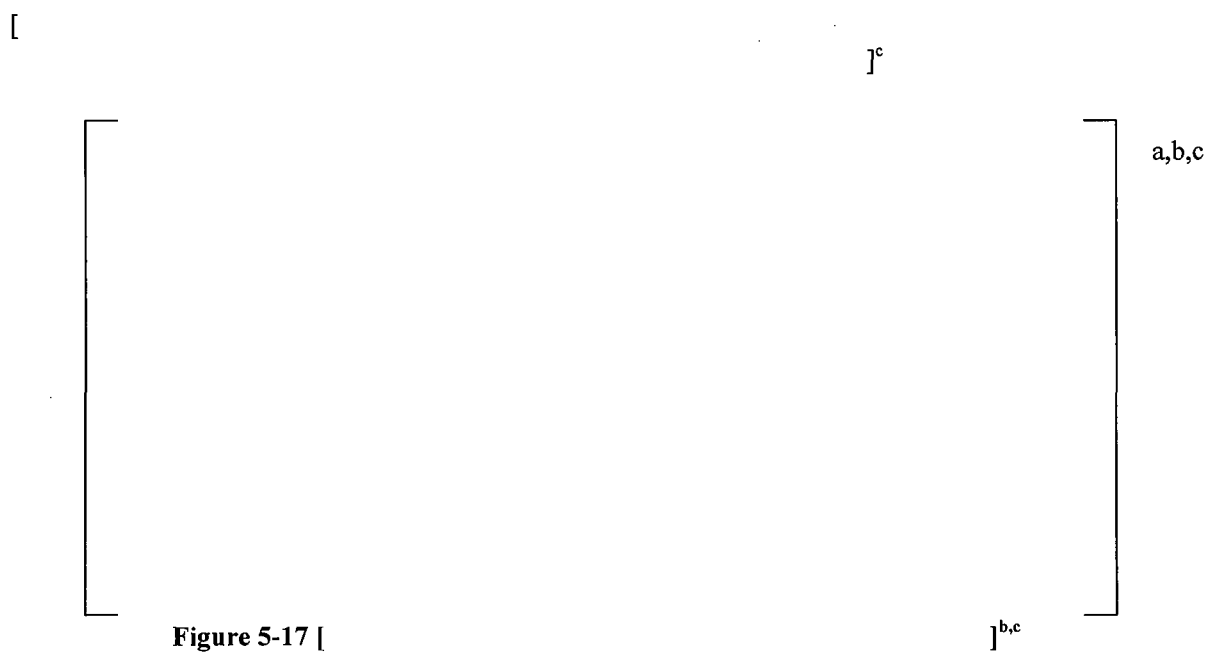


**Figure 5-15 Attenuation of MSL Data Due to Processing**

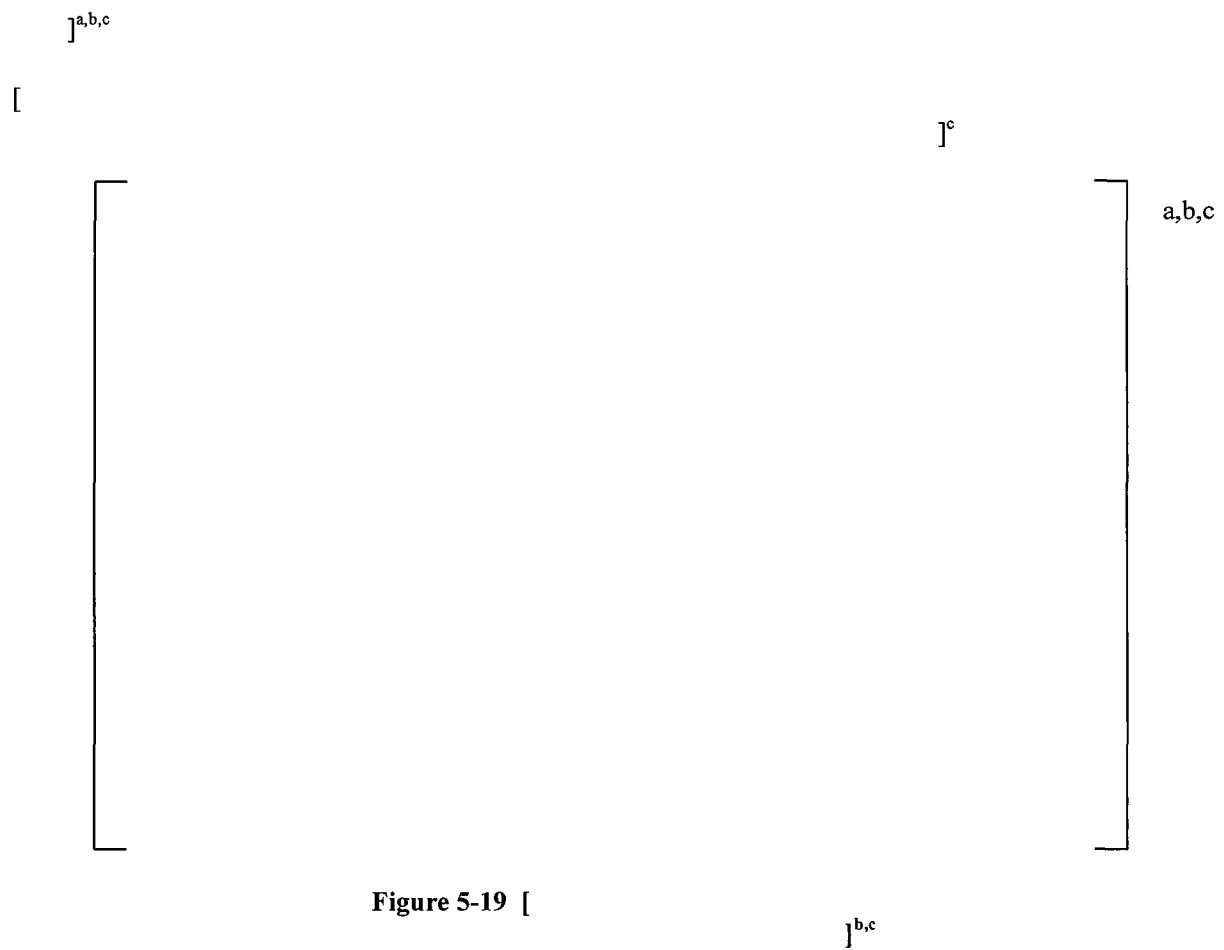


a,b,c

**Figure 5-16 Complete and Final Processed Data  
Derived MSL Pressures, 100% CLTP**









**Figure 5-20** [

] <sup>b,c</sup>



**Figure 5-21** [

] <sup>b,c</sup>

[

]<sup>b</sup>[Figure 5-  
21]<sup>c</sup>

a,b,c

**Figure 5-22** []<sup>b,c</sup>

[

]<sup>b,c</sup>

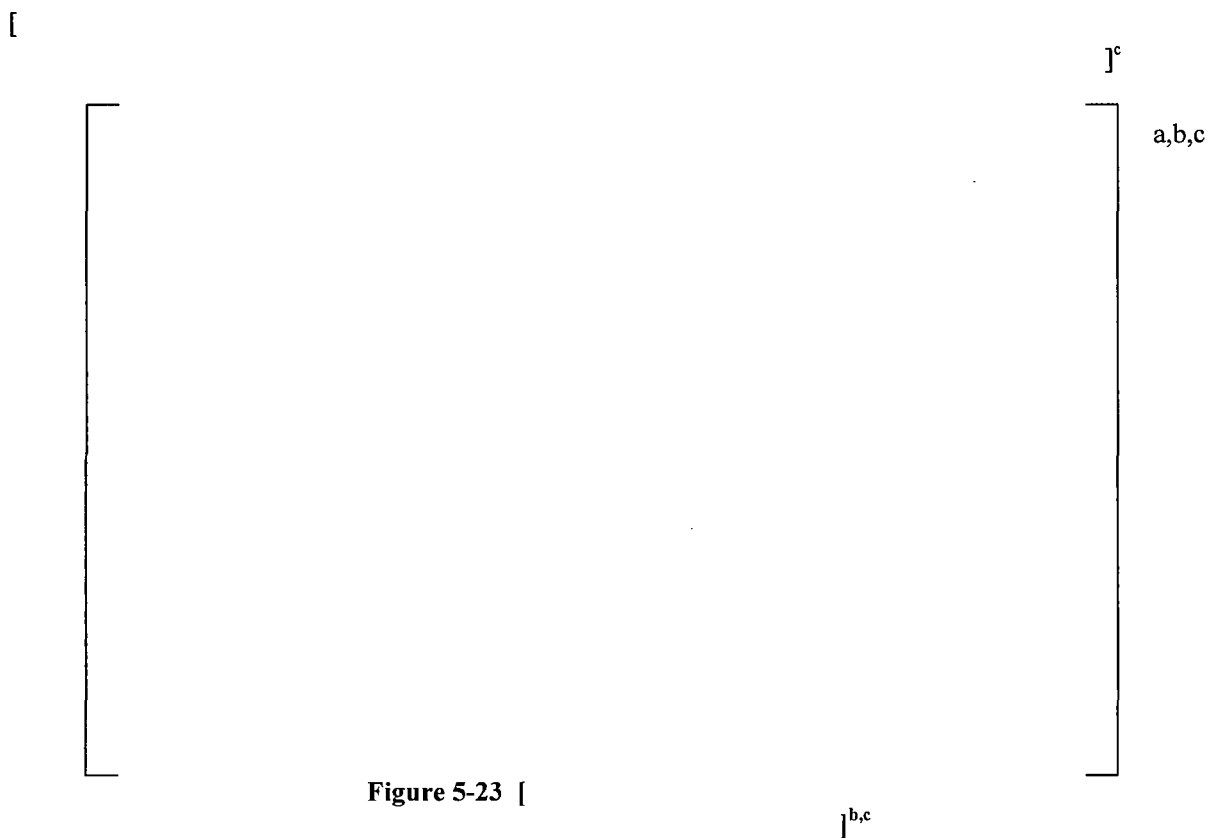




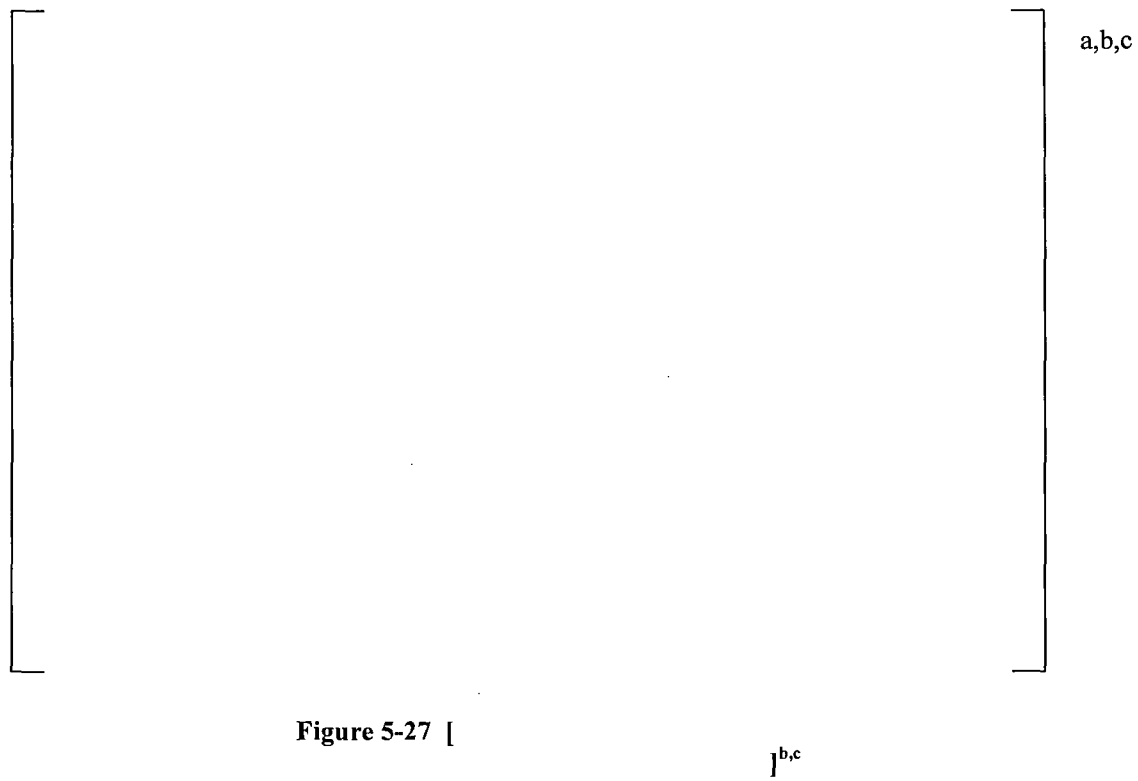
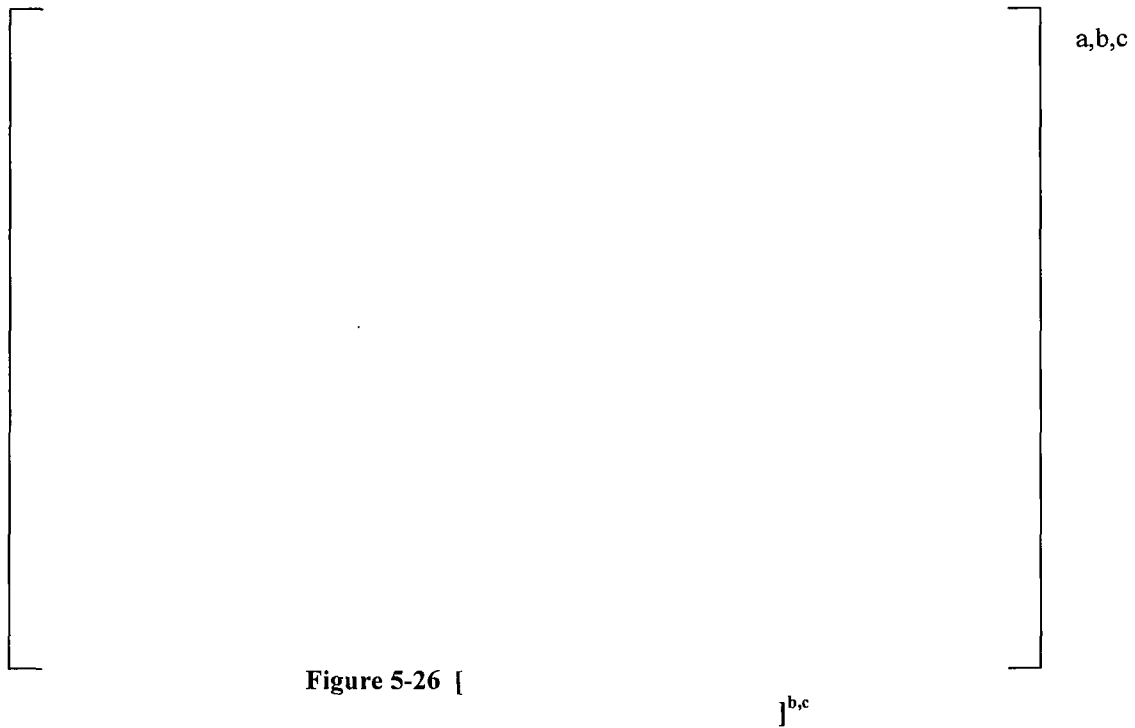
Figure 5-24 [

] <sup>b,c</sup>



Figure 5-25 [

] <sup>b,c</sup>



[

]a,b,c

[

]c

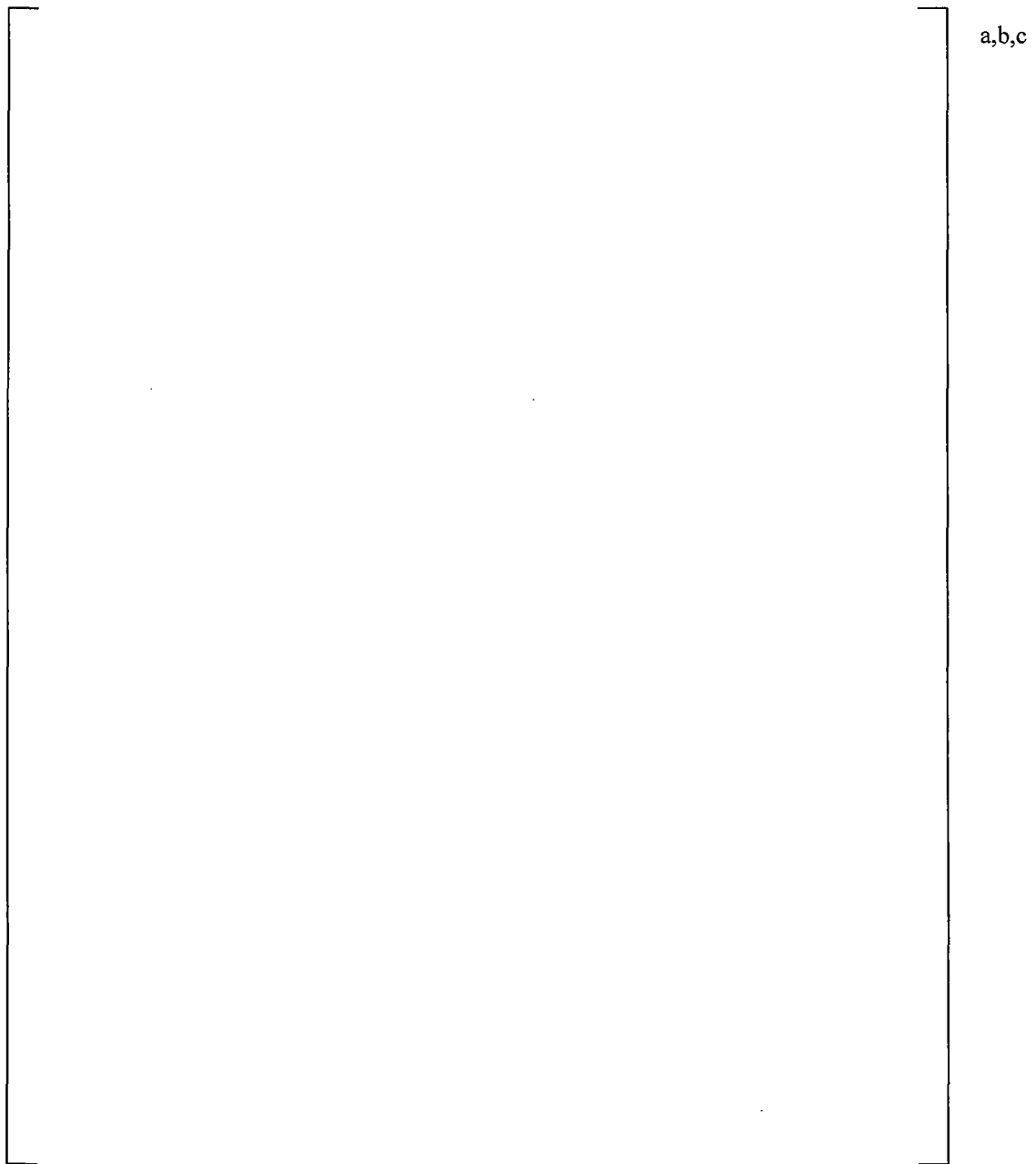


Figure 5-28 [

] b,c



## 6 CONCLUSIONS

[

$J^{a,b,c}$

The processing steps that define this methodology and that are described in this document can be summarized as follows:

- 1.) [  $J^{a,c}$
- 2.) [  $J^{a,c}$
- 3.) [  $J^{a,c}$
- 4.) [  $J^{a,c}$
- 5.) [  $J^{a,c}$

The resulting datasets are the best available representation of the actual plant data with minimal signature influence from background and noise contributions.

[

$J^{a,b,c}$

## 7 REFERENCES

1. United States Nuclear Regulatory Commission Regulatory Guide 1.20, Rev. 3, "Comprehensive Vibration Assessment Program for Reactor Internals During Preoperational and Initial Startup Testing," March 2007.
2. [ ]<sup>a,c</sup>
3. [ ]<sup>a,c</sup>
4. [ ]<sup>a,c</sup>
5. [ ]<sup>a,c</sup>
6. Structural Integrity Associates Calculation Package, MONT-11Q-302, Rev. 0, "Monticello Main Steam Line Strain Gage Data Reduction," June 27, 2007.
7. [ ]<sup>a,c</sup>
8. [ ]<sup>a,c</sup>
9. Jacob Benesty, M. Mohan Sondhi, and Yiteng Huang (Eds.), *Springer Handbook of Speech Processing*, Springer, Berlin, 2008.
10. O. Cappe, "Elimination of the Musical Noise Phenomenon with the Ephraim and Malah Noise Suppressor," *IEEE Transactions of Speech and Audio Processing* (April 1994): Vol. 2, 345-349.
11. M. C. E Rosas-Orea, M. Hernandez-Diaz, V. Alarcon-Aquino, and L. G. Guerrero-Ojeda, "A Comparative Simulation Study of Wavelet Based Denoising Algorithms," *Proceedings of the 15<sup>th</sup> International Conference on Electronics, Communications, and Computers*, 0-7695-2283-1/05, IEEE, 2005.
12. ASME, "ASME Steam Tables," Fifth Edition, 1983.

- 
13. [ ]<sup>a,c</sup>
14. Structural Integrity Associates Calculation Package, MONT-11Q-303, Rev. 1, "Monticello Main Steam Strain Gage Data Reduction," January 21, 2009.
15. Xcel Energy Design Information Transmittal, DIT-13638-10, "Extended Power Uprate Implementation," June 24, 2011.
16. X. GaoRobert, and Ruqiang Yan, *Wavelets: Theory and Applications for Manufacturing*, Springer, New York, 2010.
17. Charles M. Stein, "Estimation of the Mean of a Multivariate Normal Distribution," *The Annals of Statistics* (November 1981): Vol. 9, No. 6, 1135–1151.
18. David L. Donoho, "De-Noising by Soft-Thresholding," *IEEE Transactions on Information Theory* (May 1995): Vol. 41, No. 3.