



International Symposium  
Qualification of dynamic analyses of dams and their equipments  
and of probabilistic assessment seismic hazard in Europe  
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#### Session 4

# Investigation on the Dynamic Characteristics and Seismic Behaviors of Aratozawa Dam



# SUMMARY

**With the earthquake records over a period of about **20 years**, followings are analyzed.**

**To investigate the dynamic characteristics and their variations**

- **Fundamental frequency**
- **Acceleration amplification ratio**

**To investigate the propagation behavior of seismic motions in dam–foundation system**

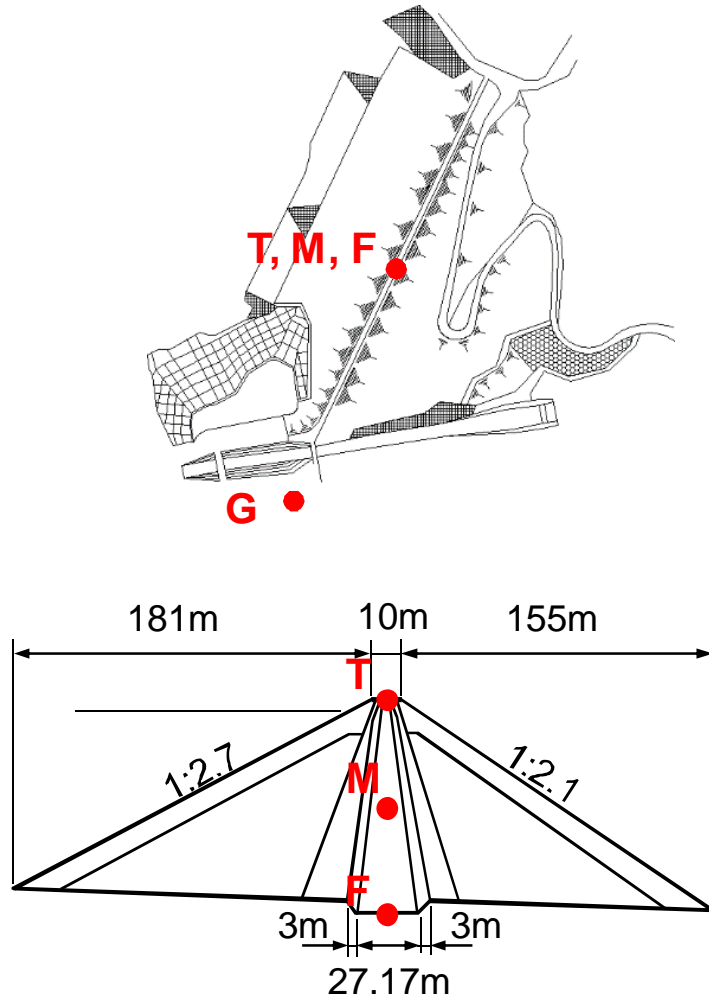
- **Cross spectrum**
- **Coherence function**

# 1. MAIN FEATURES OF ARATOSAWA DAM

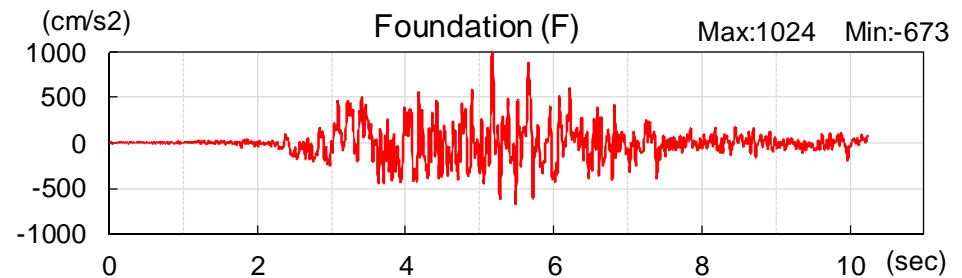
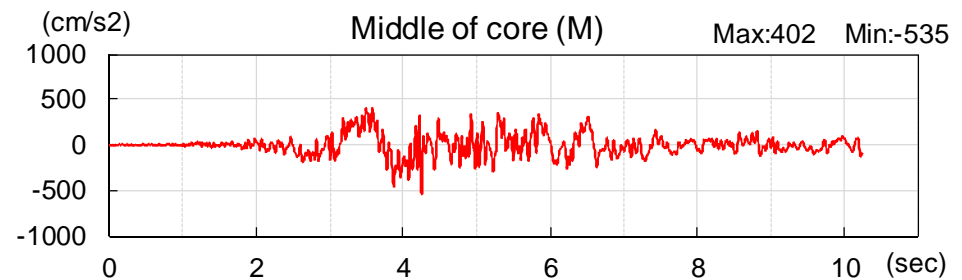
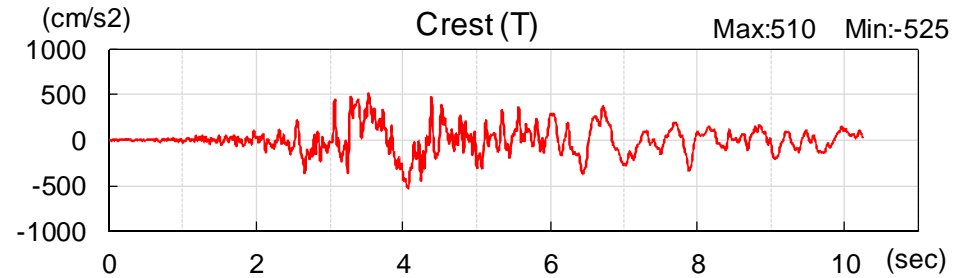


<b>Dam type</b>	<b>Rockfill dam with central clay core</b>
<b>Dam height</b>	<b>74.4m</b>
<b>Crest length</b>	<b>413.7m</b>
<b>Crest width</b>	<b>10.0m</b>
<b>Slope gradients</b>	<b>Upstream: 1:2.7 Downstream: 1:2.1</b>
<b>Design seismic coefficient</b>	<b>0.15 (dam body), 0.18 (intake tower, bridge), 0.16 (spillway)</b>

# 2. EARTHQUAKE MONITORING

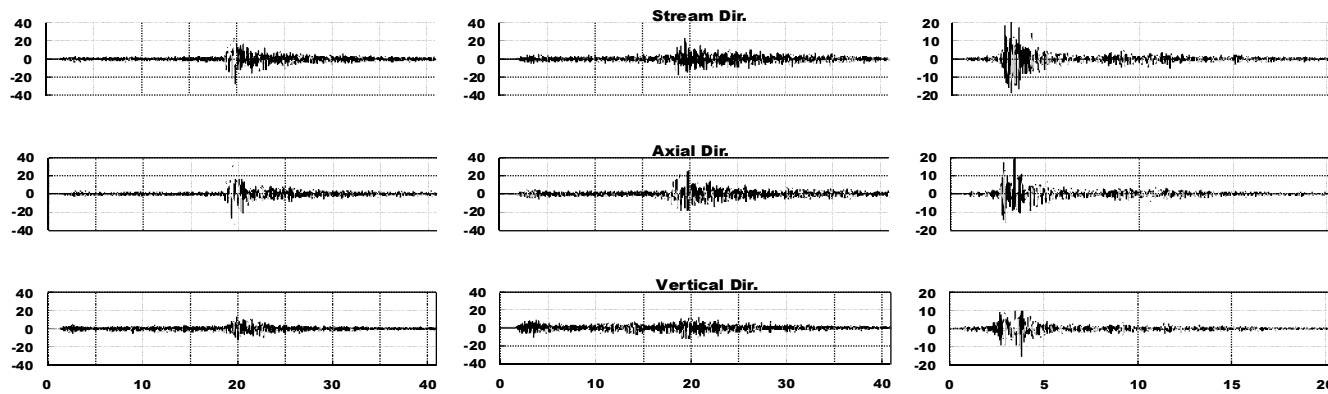


**Locations of Seismographs**

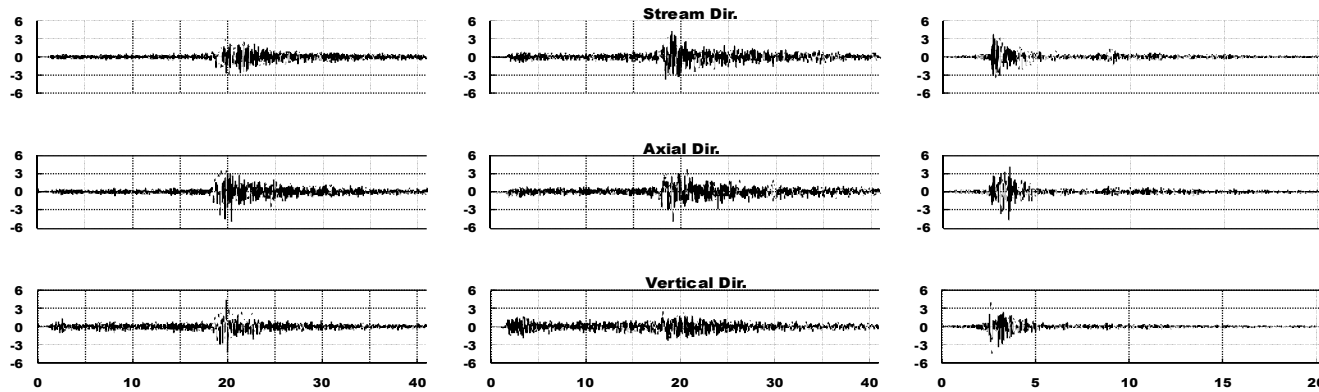


**Earthquake Records in Stream Dir.  
Iwate-Miyagi Nairiku Earthquake, 2008**

Period	Number of Records	$A_{max}(cm/s^2)$
1992 - 2013	> 1500	
	> 500	>10
	37	>100



(a) Crest (T)



(b) Foundation (F)

1997/12/07 12:50:41

1999/11/15 10:34:35

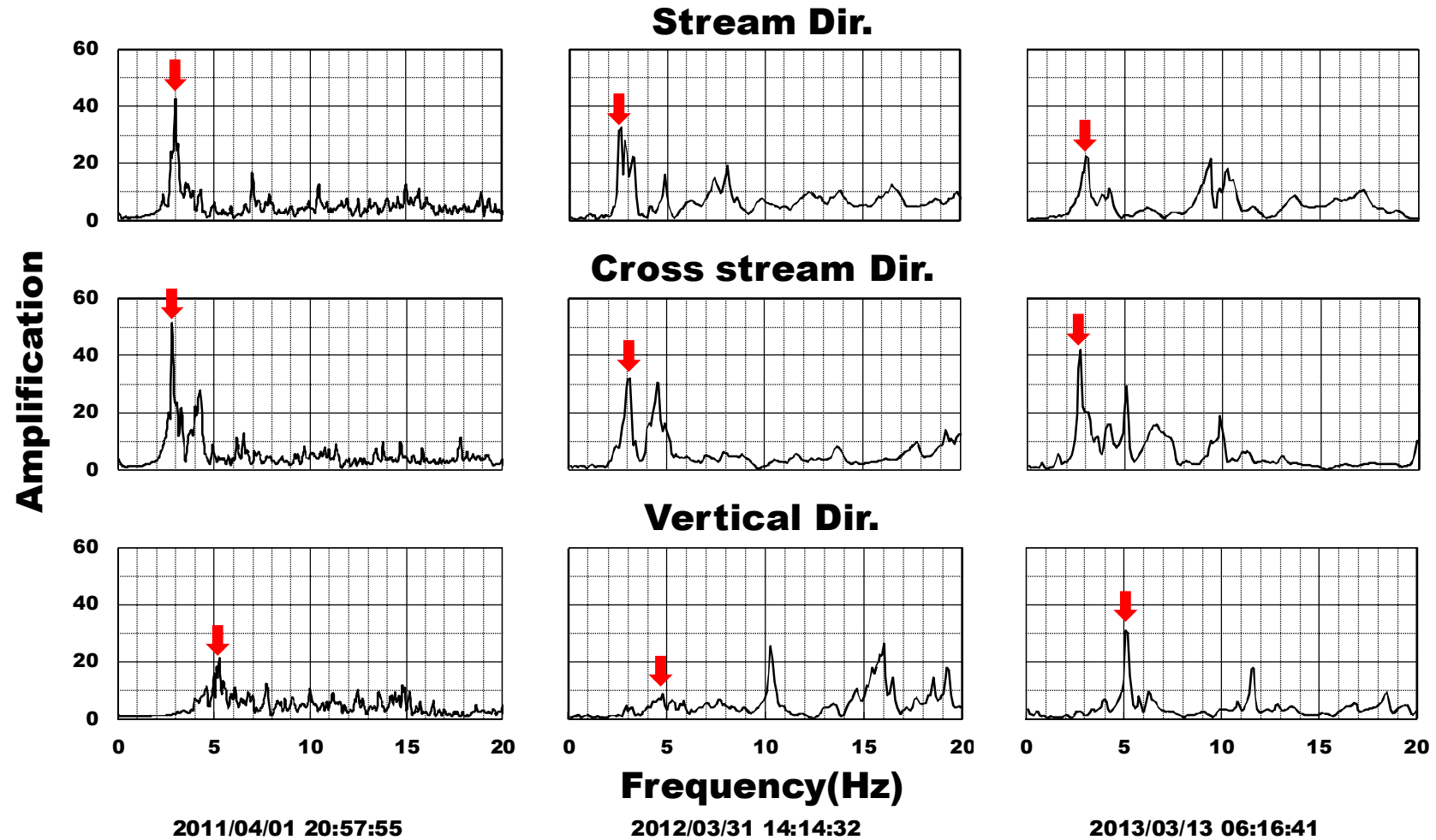
2000/02/18 22:38:47

### 3. THE WORK WE'VE DONE

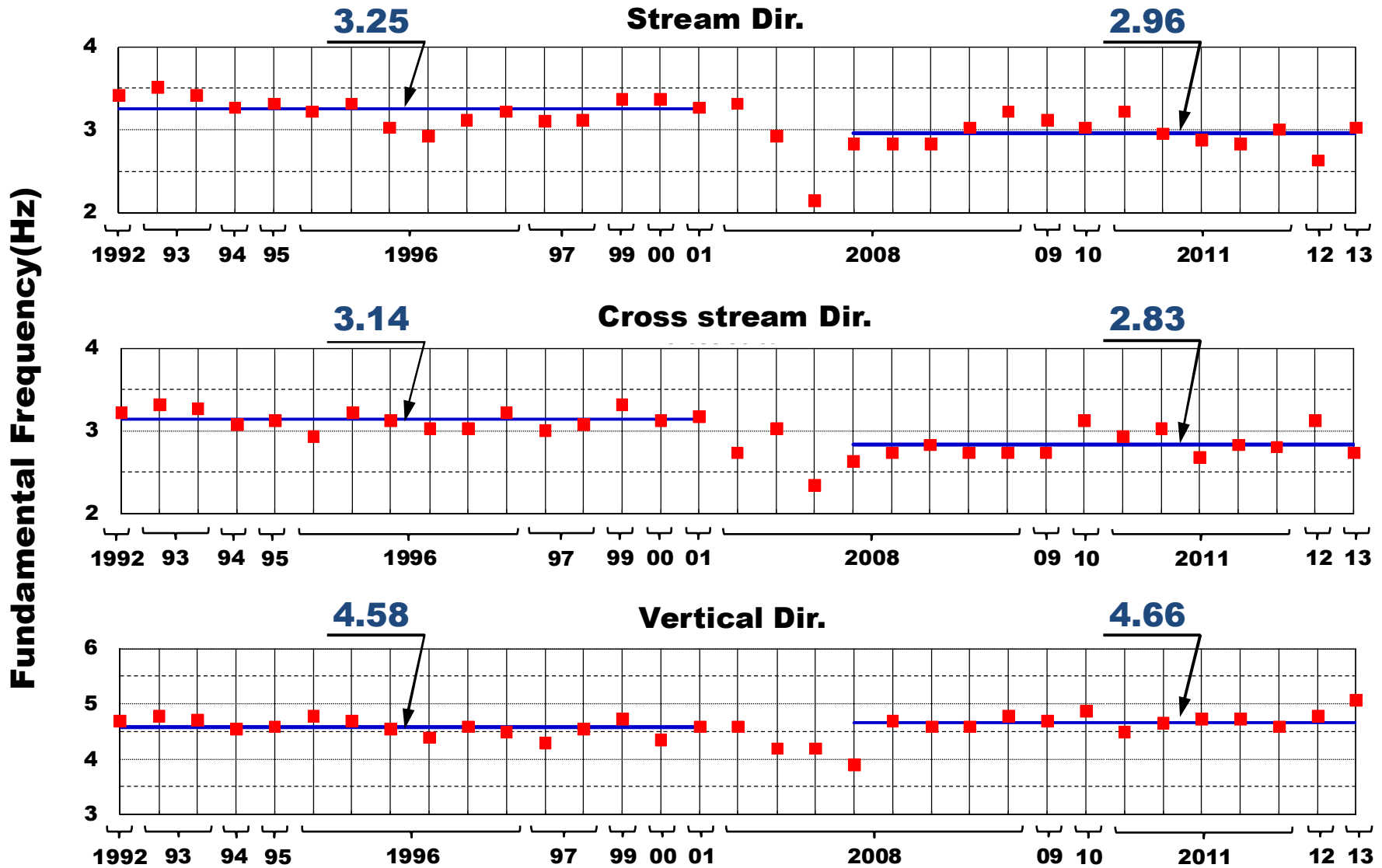
Analyses	Main objectives	Records used
Spectrum and transfer function	To investigate the variation of the <b>fundamental frequency</b> of the dam	33 records $2 \text{ cm/s}^2 < A_{\max} < 20 \text{ cm/s}^2$
Investigation on the amplification ratio	To find the variation of <b>amplification ratio</b> of the dam body	18 records 4, $A_{\max} \approx 30 \text{ cm/s}^2$ 3, $A_{\max} \approx 75$ 3, $A_{\max} \approx 100$ 4, $A_{\max} \approx 120$ 4, $A_{\max} > 150$
Cross spectrum and coherence function	To investigate the <b>propagation behavior</b> of seismic motion in dam – foundation system	Same as above

# 4. SPECTRUM & TRANSFER FUNCTION

## 4-1 Transfer Function



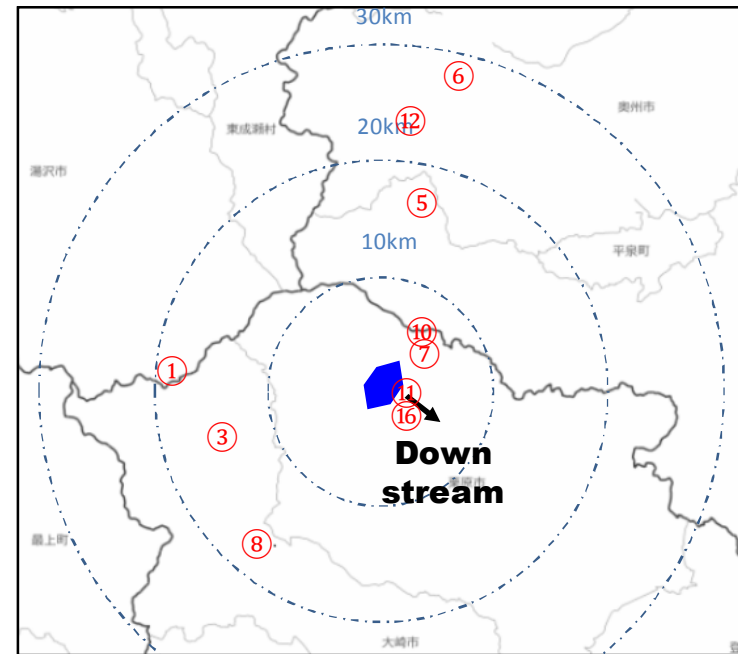
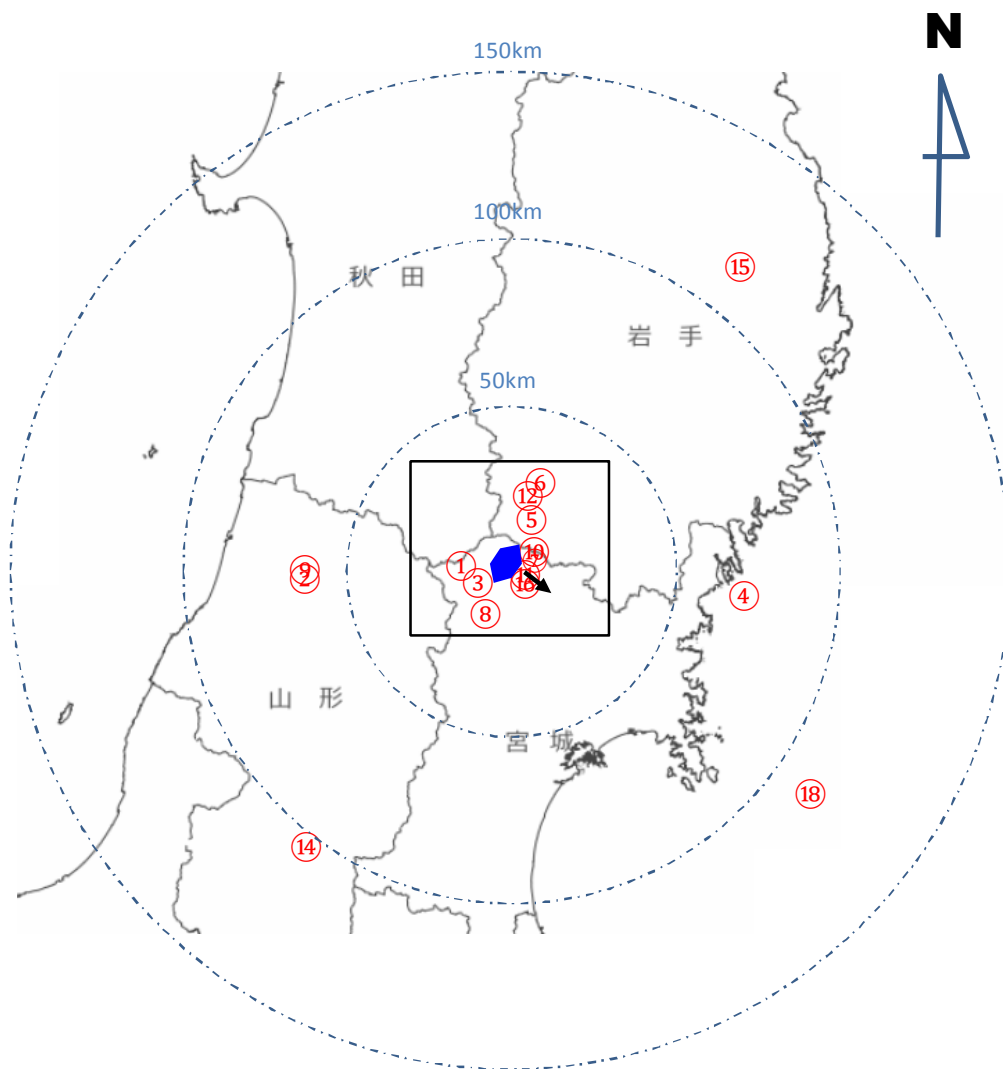
# 4-2 Fundamental Frequencies of the Dam





# 5. AMPLIFICATION RATIO ANALYSIS

## 5-1 Epicenters of the Selected Earthquakes



**18 records before and after 2008**

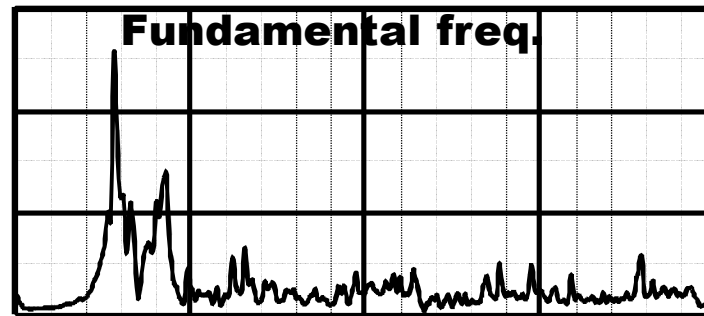
- ⑬ 4,  $A_{\max} \approx 30 \text{ cm/s}^2$
- ⑭ 3,  $A_{\max} \approx 75$
- ⑮ 3,  $A_{\max} \approx 100$
- ⑯ 4,  $A_{\max} \approx 120$
- ⑰ 4,  $A_{\max} > 150$

## 5-2 Features of the Selected Earthquakes

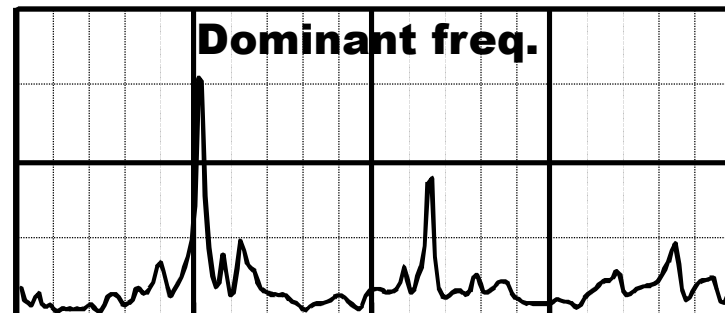
No.	Time of occurrence	M	Focal depth (km)	$A_{\max}$ of found. (cm/s <sup>2</sup> )
1	1996/08/11 03:12	6.1	9	28
2	1996/08/11 08:10	5.8	10	36
3	1996/08/11 15:01	4.9	10	30
4	2003/05/26 18:24	7.1	72	114
5	2008/06/14 08:43	7.2	8	1024
6	2008/06/14 09:00	4.2	11	99
7	2008/06/14 09:01	4.0	7	482
8	2008/06/14 09:14	3.6	4	151
9	2008/06/14 09:20	5.7	7	76
10	2008/06/14 10:40	4.8	7	120
11	2008/06/14 12:09	4.1	8	92
12	2008/06/14 12:10	4.8	9	79
13	2008/06/14 19:11	4.1	8	229
14	2008/06/16 23:14	5.3	7	76
15	2008/07/24 00:26	6.8	108	27
16	2008/09/25 15:04	4.1	6	119
17	2011/03/11 14:46	9.0	24	102
18	2011/04/07 23:32	7.2	66	120

## 5-3 Investigation Method

$$\text{Amplification ratio} = \frac{\text{Peak acc. of crest}}{\text{Peak acc. of foundation}}$$



**Transfer function of dam body**

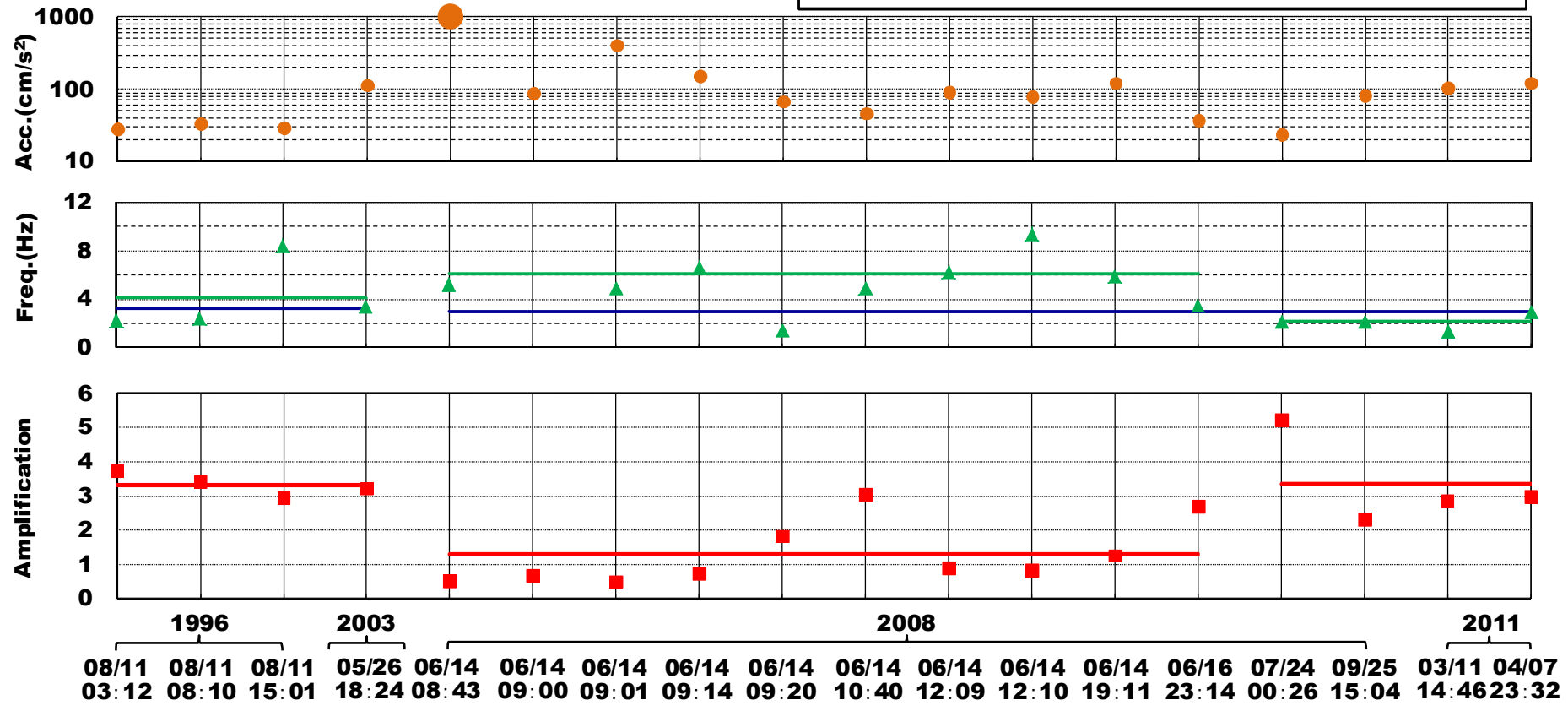


0 5 10 15 20

**Fourier spectrum of ground motion**

# 5-4 Amplification Ratio(1/4)

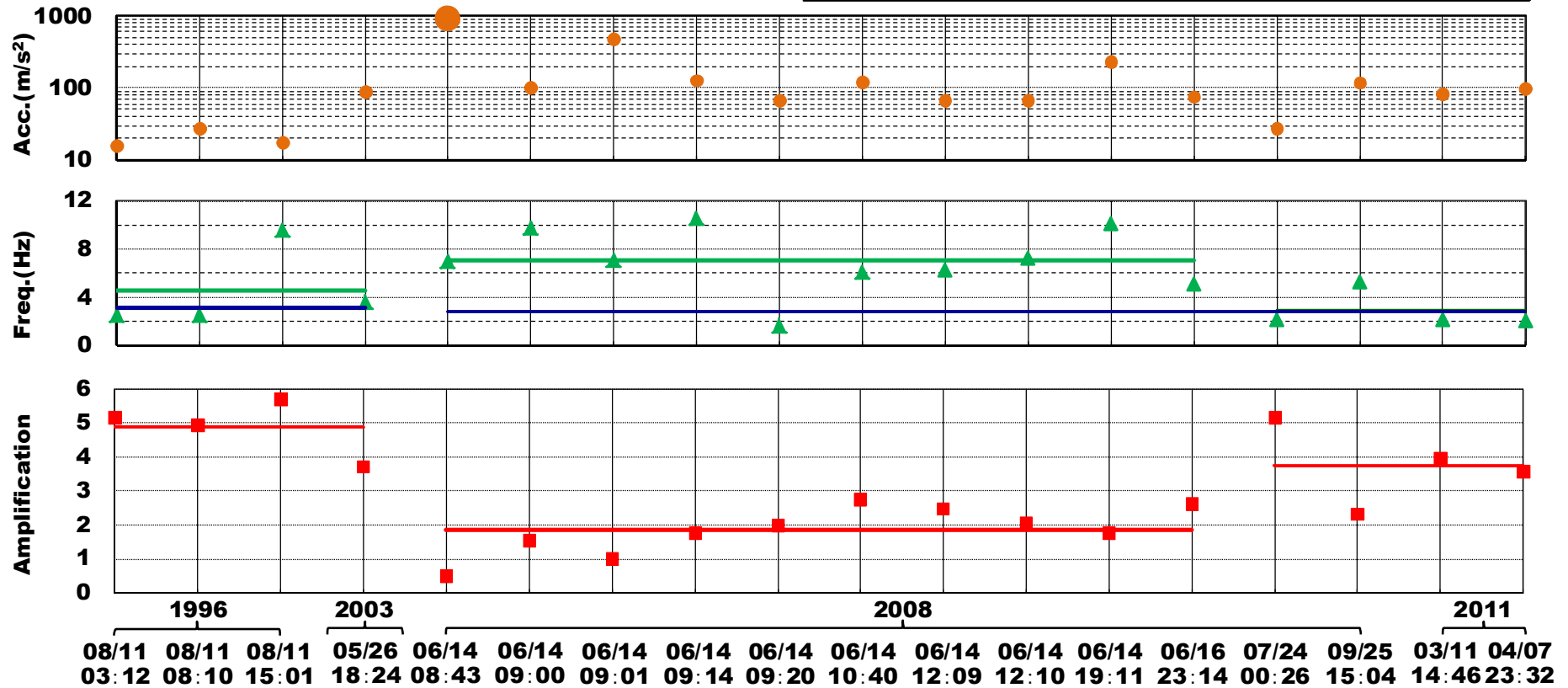
## Stream Direction



# 5-4 Amplification Ratio(2/4)

## Cross Stream Direction

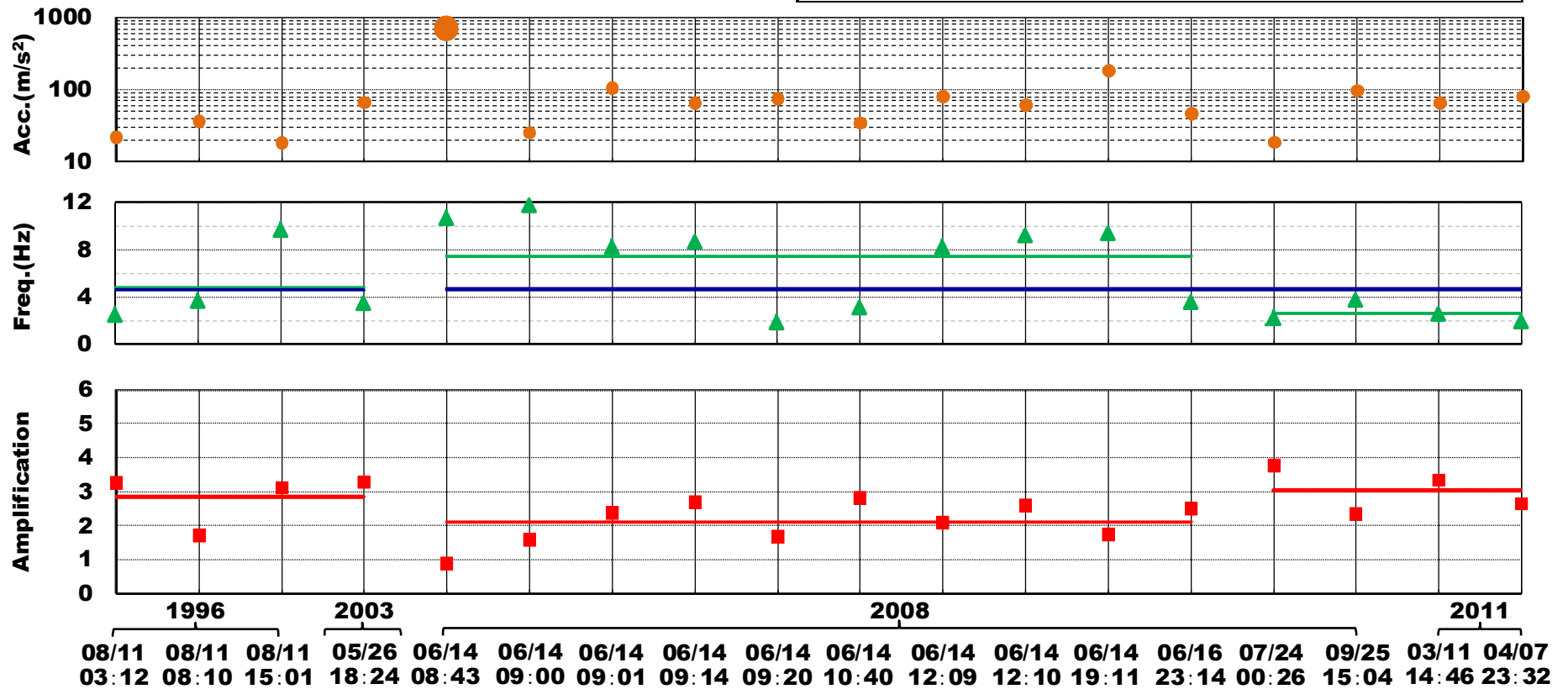
- Max. acc. of the foundation
- ▲ Dominant freq. of the earthquake
- Fundamental freq. of the dam
- Amplification ratio of the dam



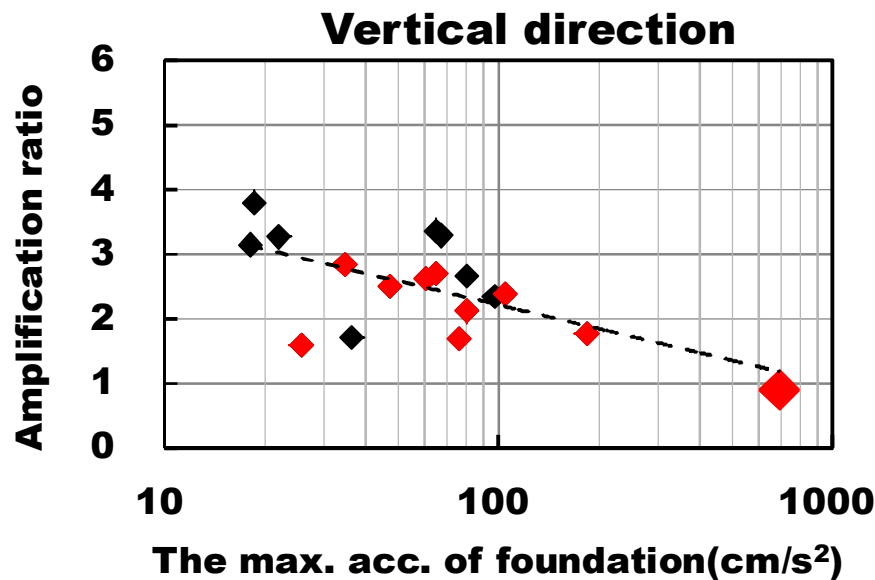
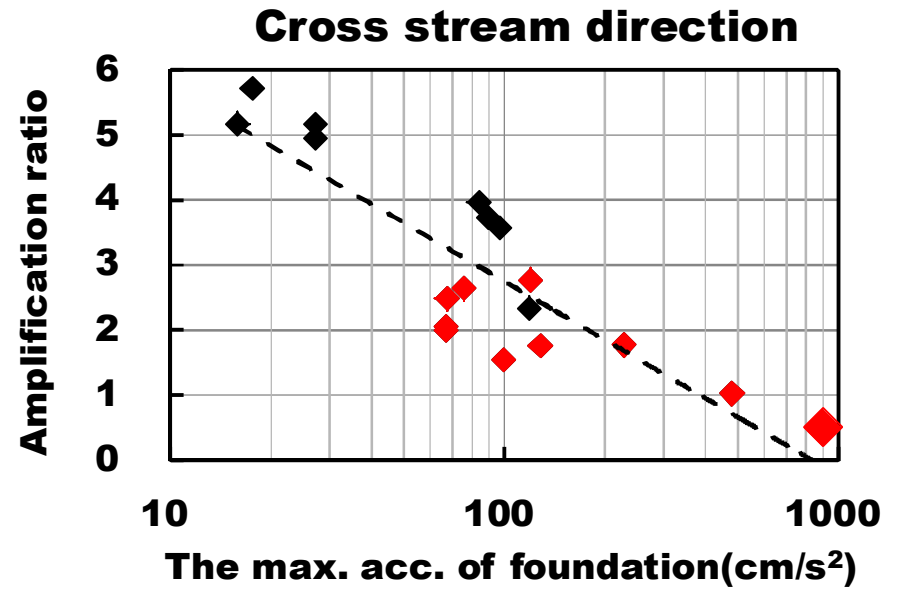
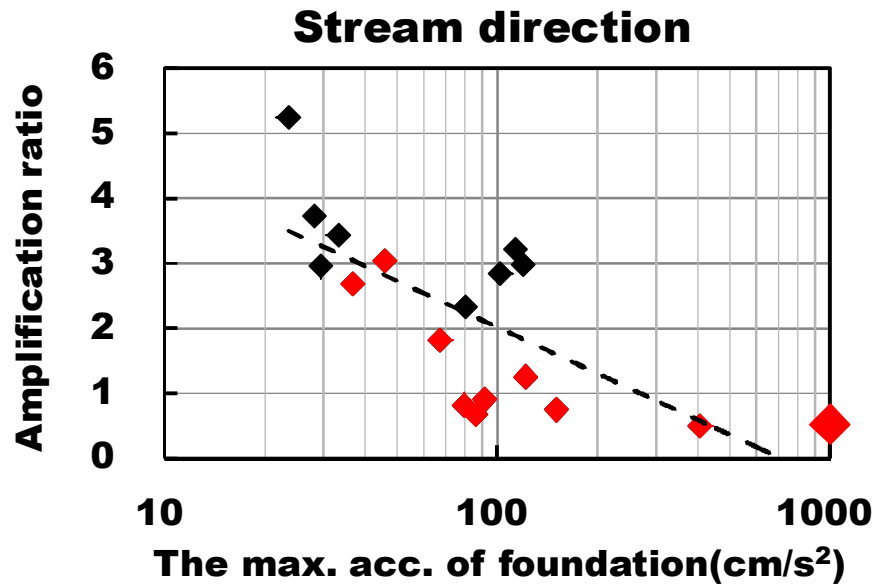
# 5-4 Amplification Ratio(3/4)

## Vertical Direction

- Max. acc. of the foundation
- ▲ Dominant freq. of the earthquake
- Fundamental freq. of the dam
- Amplification ratio of the dam



# 5-4 Amplification Ratio(4/4)



- ◆ Other earthquakes
- ◆ 2008 Earthquake and its aftershocks
- Approximate line

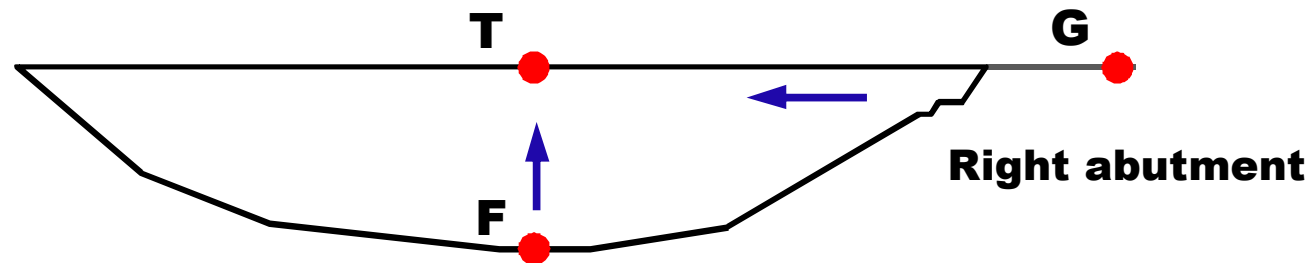
# 6. PROPAGATION BEHAVIOR OF SEISMIC MOTION

## 6-1 Analytic Methods

assuming two propagation paths

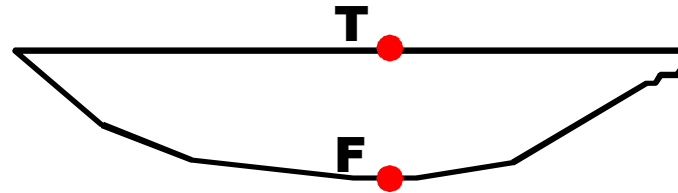
$$F \rightarrow T \quad \text{and} \quad G \rightarrow T$$

- 1) cross spectrum
- 2) coherence function
- 3) transfer function





## Definition:



### Transfer Function

$$D_{TF} = S_T / S_F$$

### Cross Spectrum

$$W_{TF} = S_T \cdot S_F$$

### Coherence Function

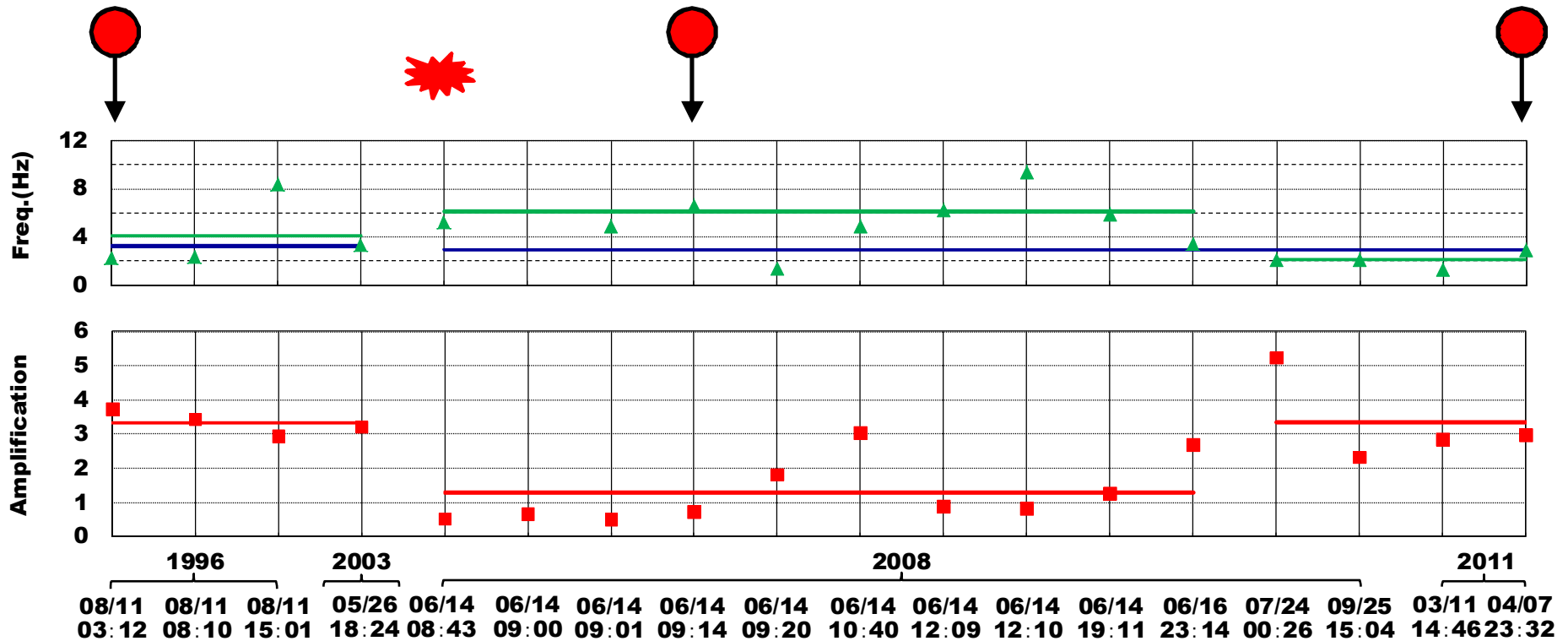
$$C_{TF} = |W_{TF}|^2 / (W_{TT} \cdot W_{FF})$$

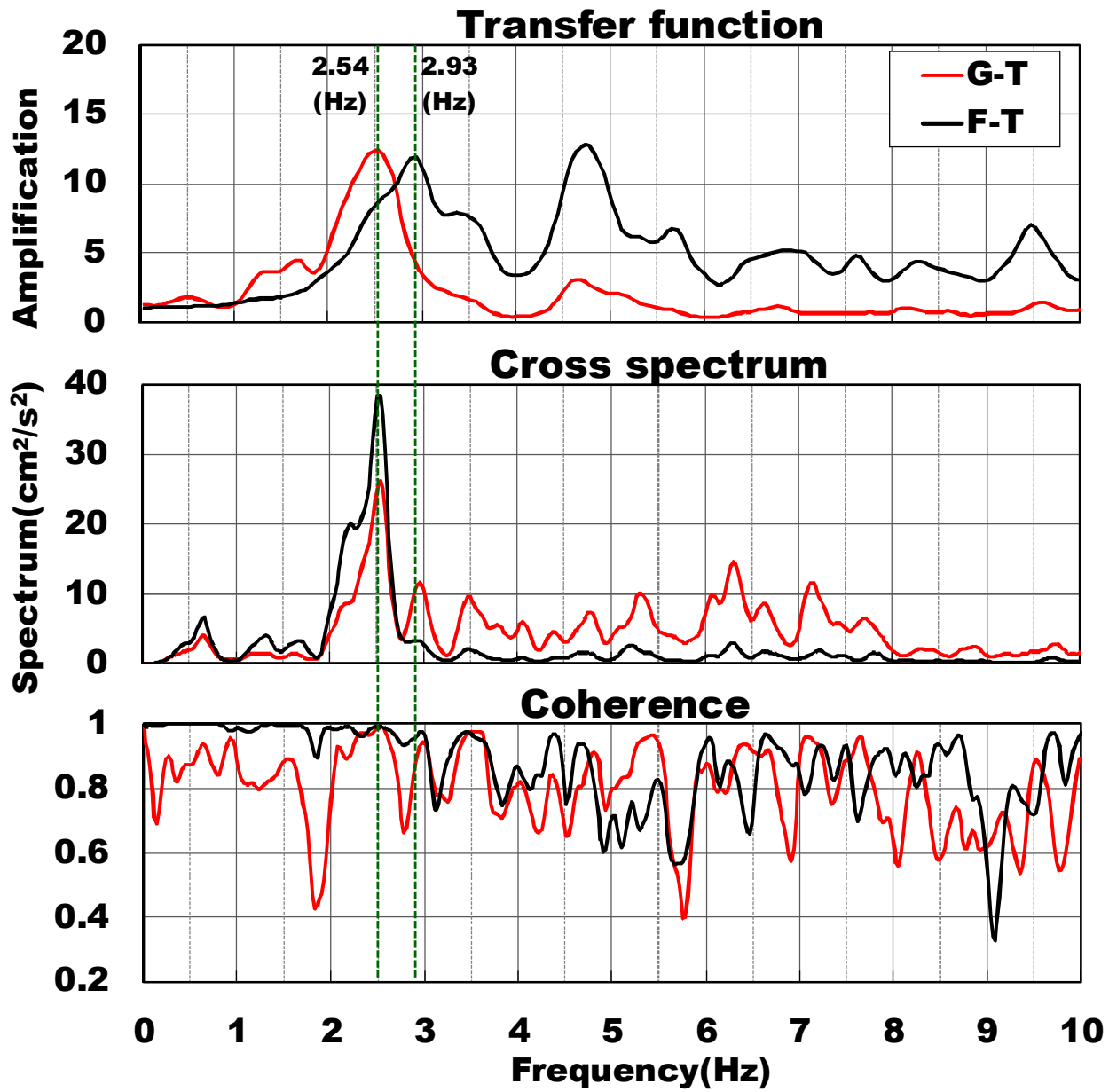
# Earthquakes to be analyzed

**Original status**

**20min after the strong earthquake**

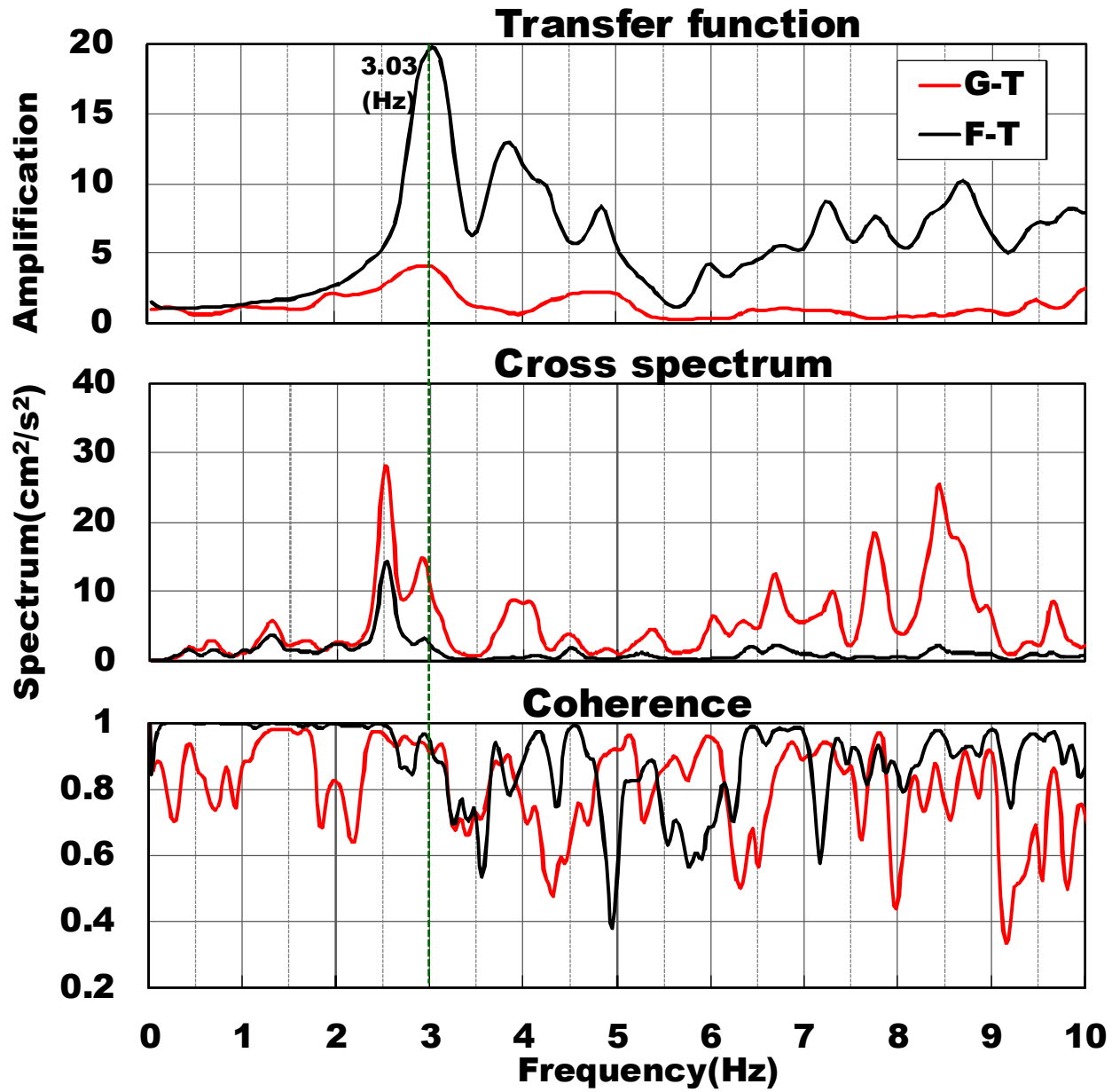
**3 years after ..**





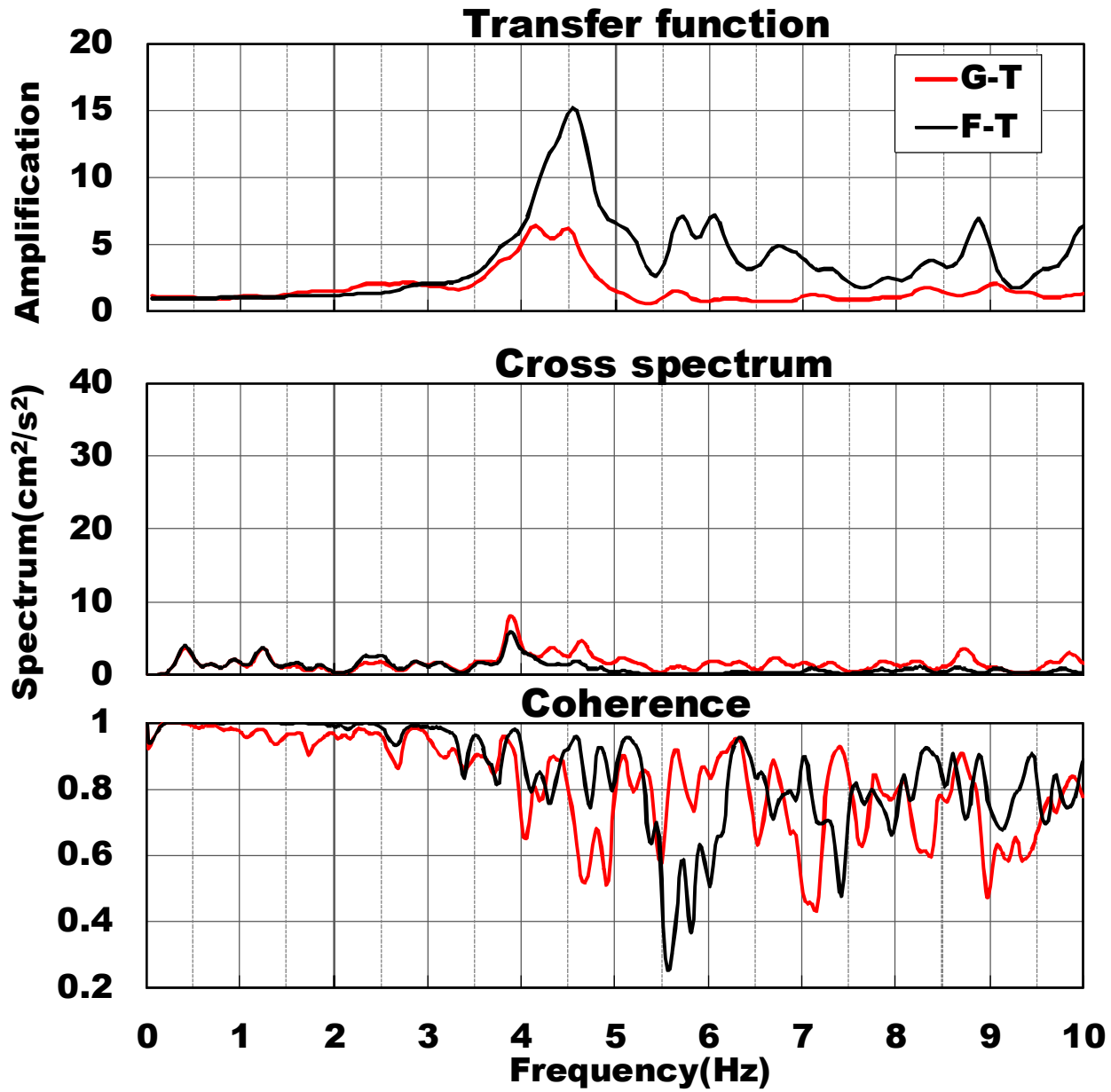
**Original  
status  
in 1996**

**Stream direction (Aug.11,03:12, 1996)**



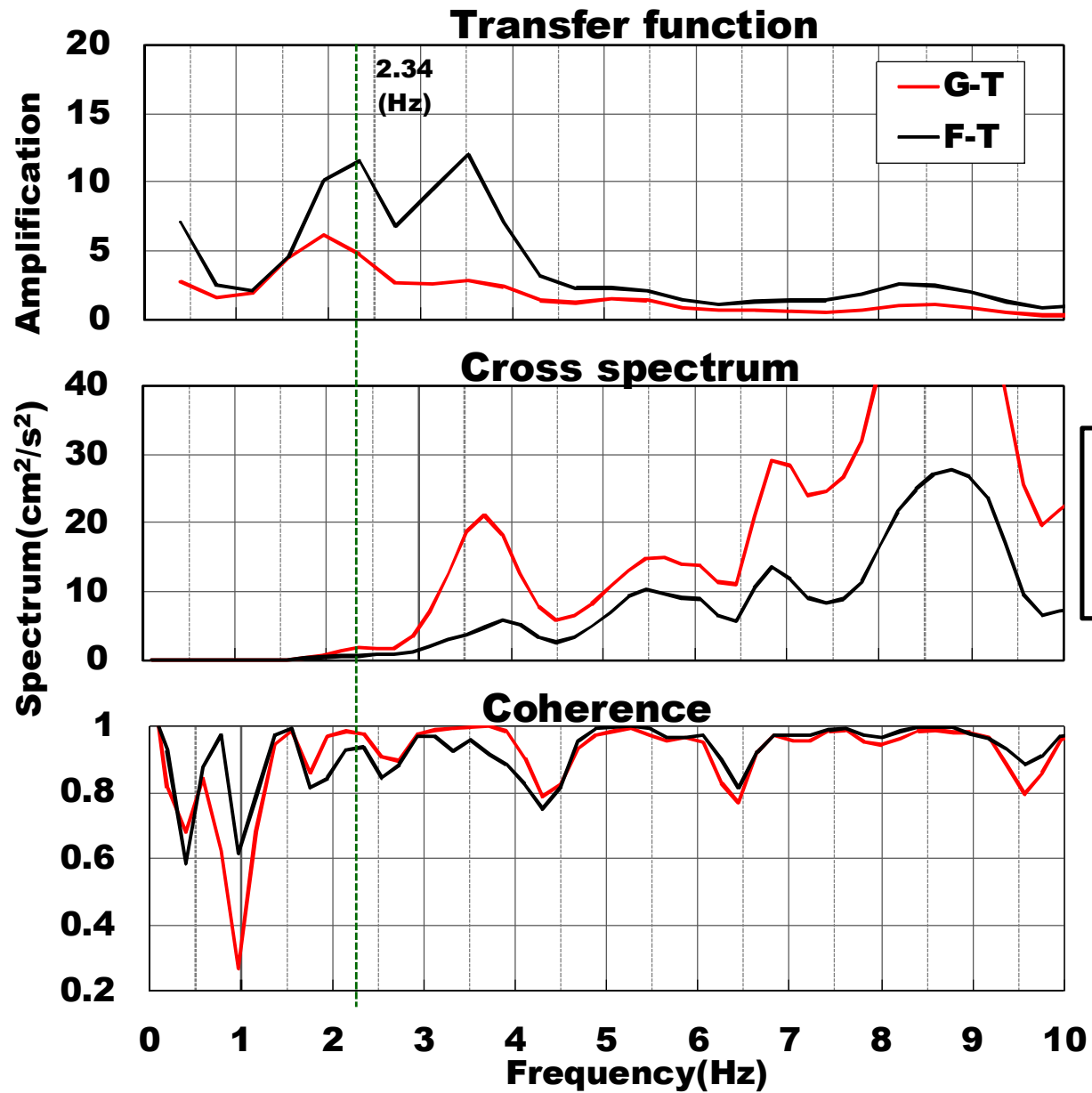
**Original  
status  
in 1996**

**Cross stream direction (Aug.11,03:12, 1996)**

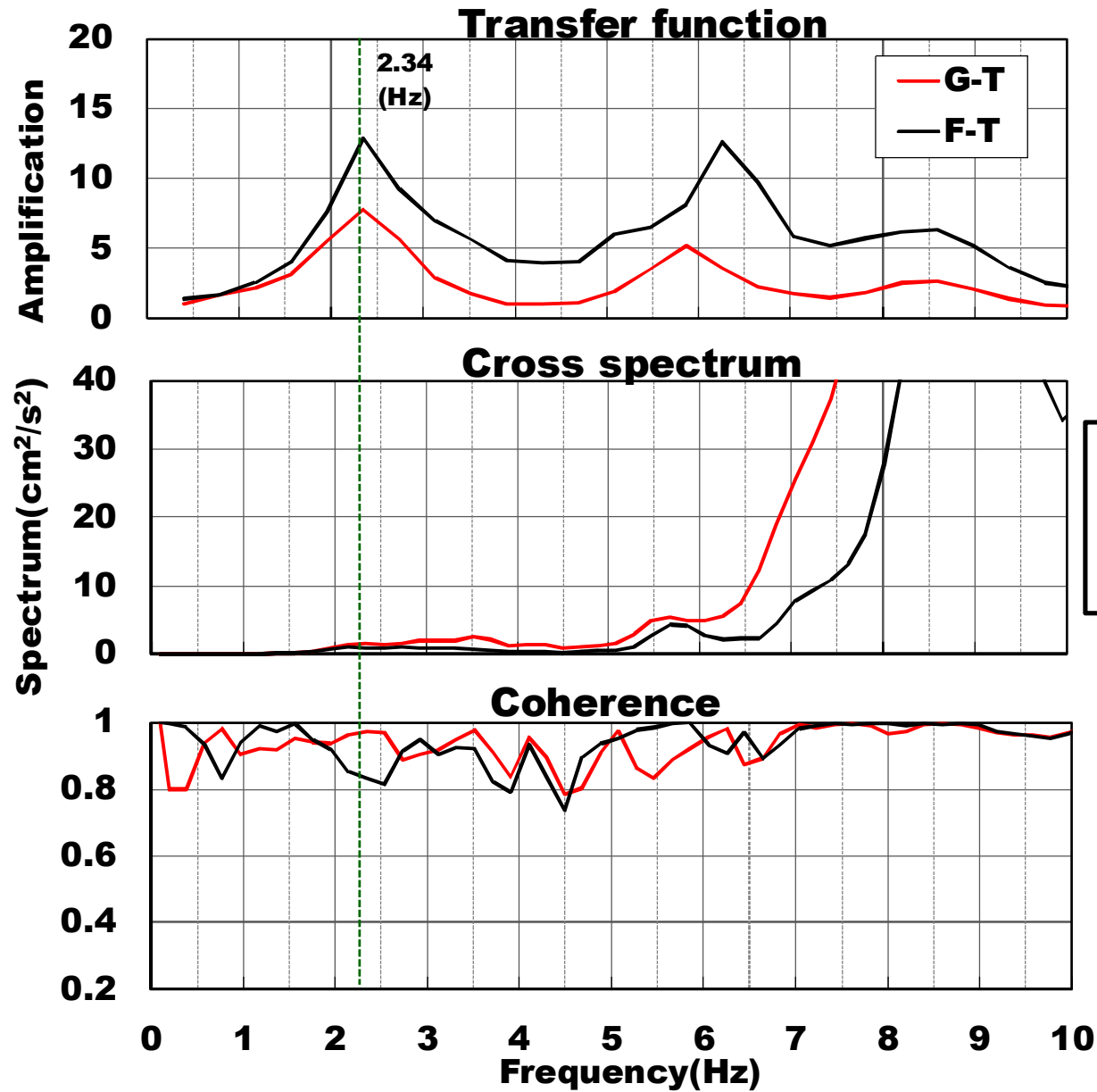


**Original  
status  
in 1996**

**Vertical direction (Aug.11,03:12, 1996)**

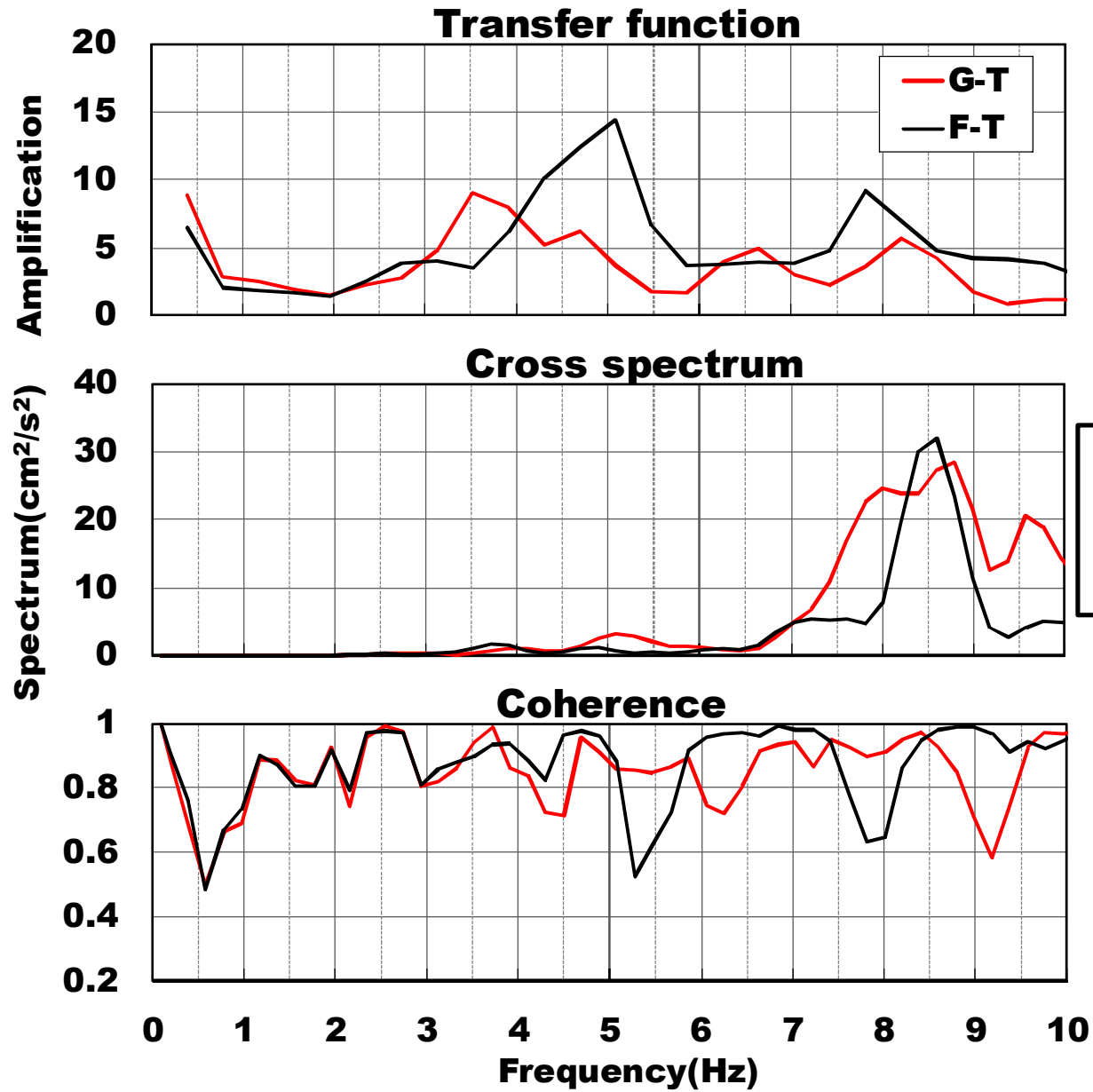


**Stream direction (June 14,09:14, 2008)**



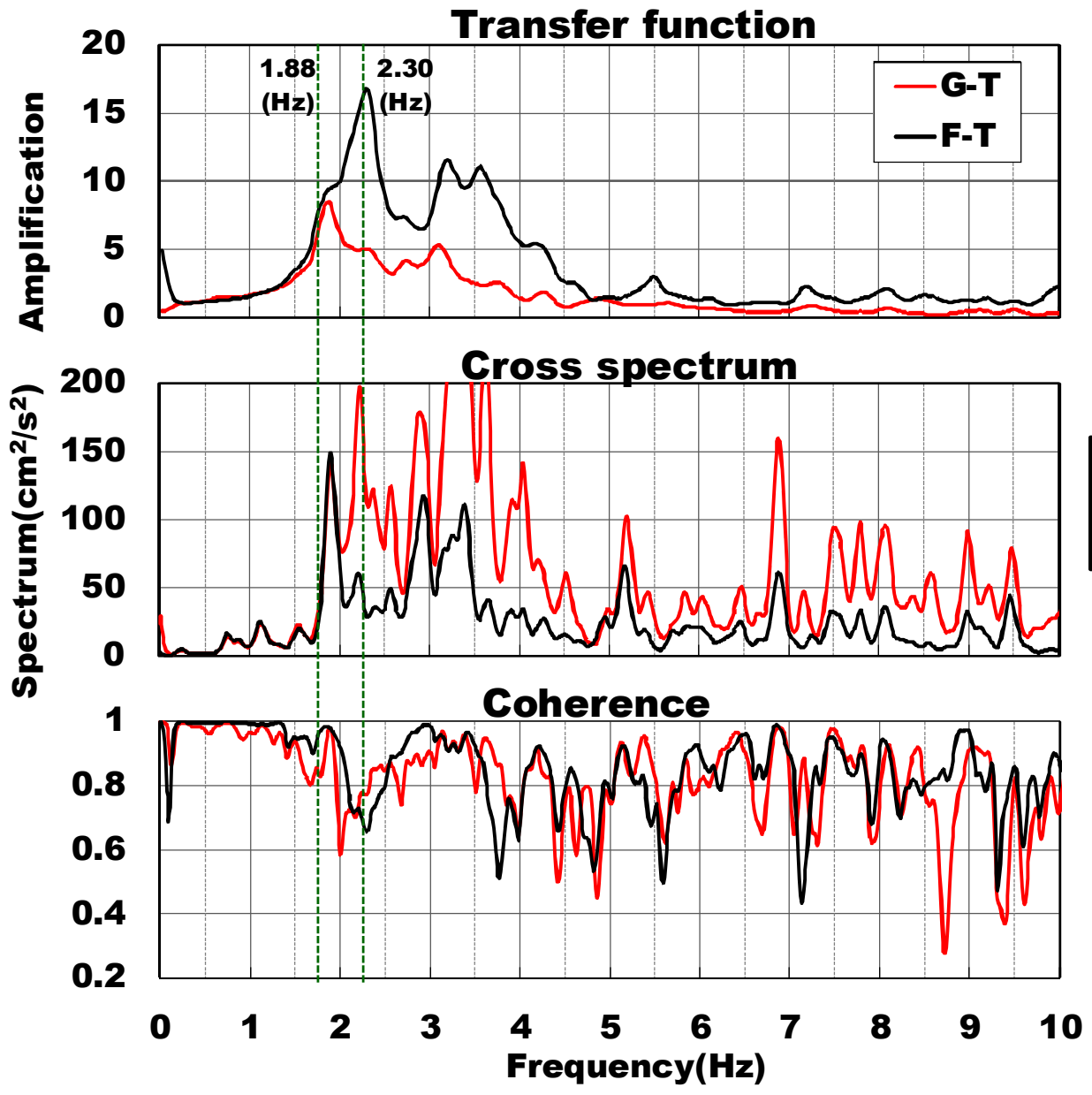
**Just after  
the strong  
earthquake**

**Cross stream direction (June 14,09:14, 2008)**



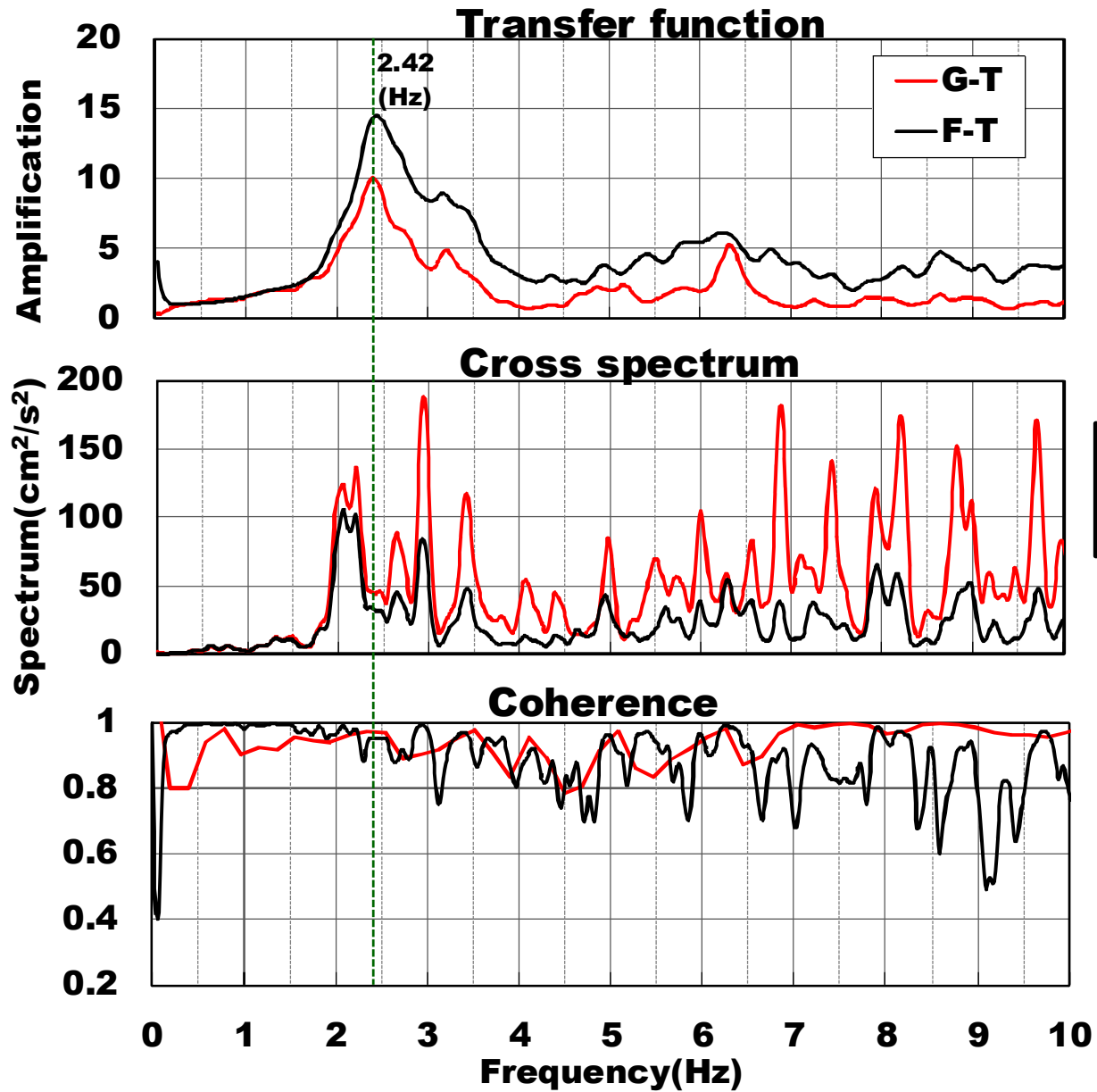
**Vertical direction (June 14,09:14, 2008)**





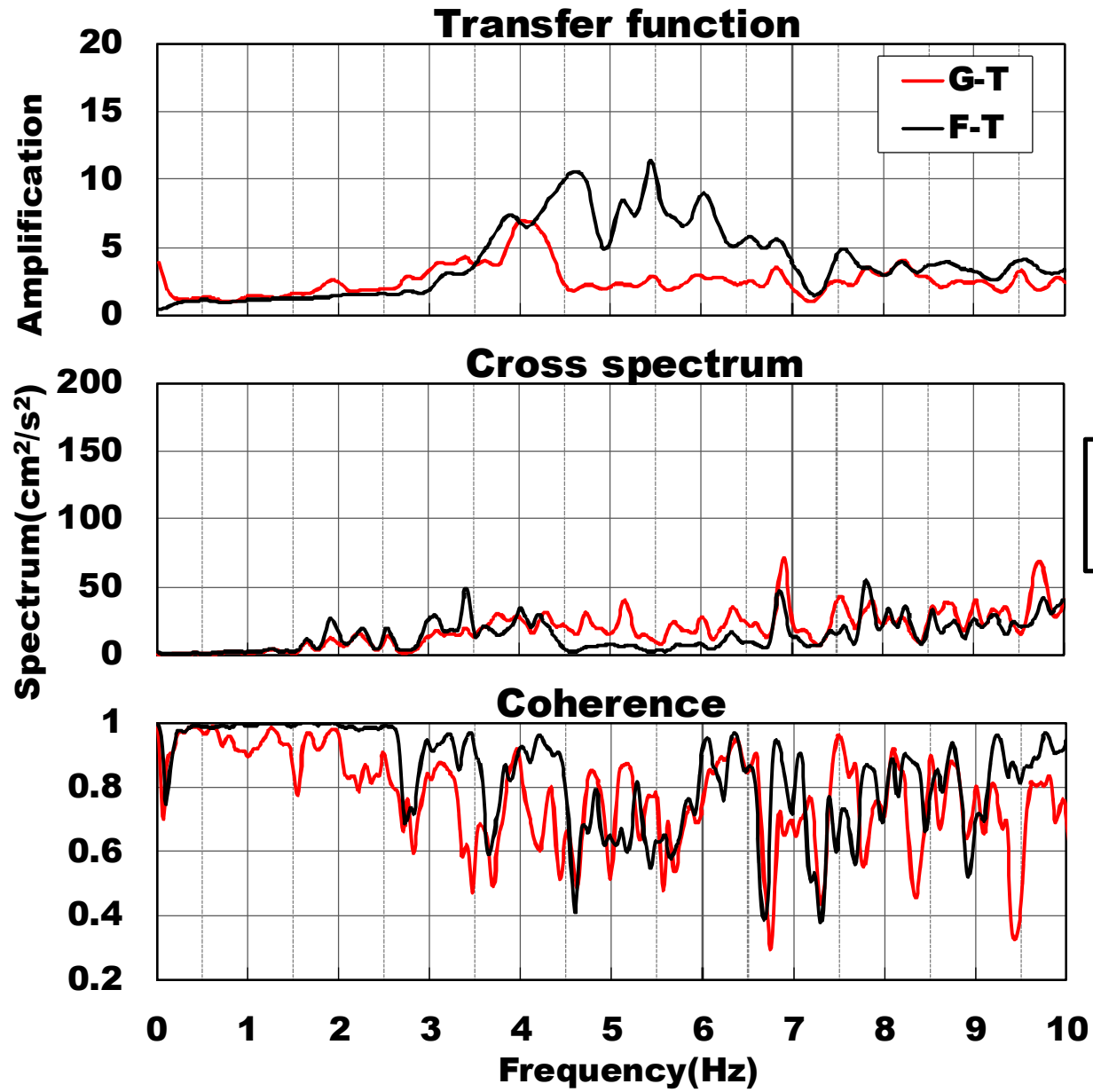
**About 3 years later**

**Stream direction (April 7, 23:32, 2011)**



**About 3 years later**

**Cross stream direction (April 7,23:32, 2011)**



**About 3  
years later**

**Vertical direction (April 7, 23:32, 2011)**

# CONCLUDING REMARKS

- ◆ **The Earthquake in 2008 caused a sharp drop of the fundamental frequencies, which later recovered, but accompanied with anisotropy.**
- ◆ **The amplification ratio show the same variation tendency as that of the fundamental frequency.**
- ◆ **In the low frequency domain up to the fundamental frequency, the effect of the seismic motions of the lower bedrock is greater than that of the abutment. While, it shows opposite tendency in the higher frequency domain.**

**THANK YOU  
FOR YOUR ATTENTION**

