

以NB-IoT與免控制點位移量測技術進行 水土保持設施之安全檢測與評估

報告者：廖國偉

國立臺灣大學生物環境系統工程學研究所 副教授

大綱

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 目標

 智慧感測元件之開發

 物聯網(IoT)之建置

 免控制點演算法之開發

 防砂壩頂位移之重建

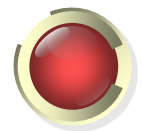
 基於位移重建之防砂壩系統識別分析
(容量分析)

 基於位移重建之防砂壩機器學習分析
(需求分析)

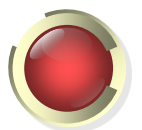
 防砂壩之安全分析

 結論

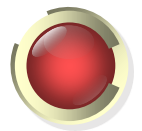
背景



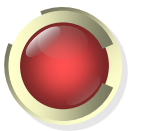
治山防洪構造物巡查表單 【水保局96年度之治山防災工程維護機制計畫案】



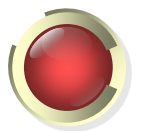
水保設施現地檢測的DER評分 【水保局101年度的水土保持設施耐久性分析與延壽策略研擬計畫案】



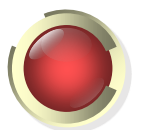
目視檢測：工程師經驗(+)、客觀性(-)



工程人員須親赴現場檢測與評估(-)

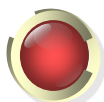


大型防砂設施構造物之巡檢



MEMS、NB-IoT、人工智慧

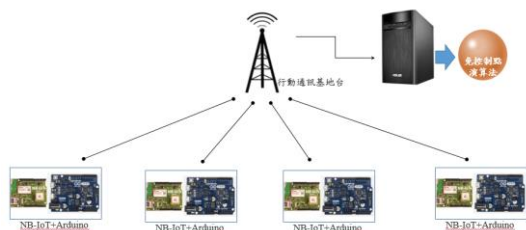
目標

-  利用NB-IoT與免控制點位移量測技術進行重要水土保持設施初步安全評估
可行性研究與開發
-  位移是理想指標?為何量取加速度?傾斜角度如何?
-  靜態與動態指標，何者更適合水保設施?

分析流程與架構示意圖

NB-IoT免控制點壩頂位移之重建

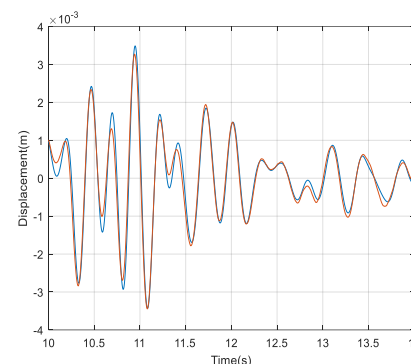
- 智慧感測器與物聯網之建立
- 免控制點演算法之建立與驗證



防砂壩之安全分析

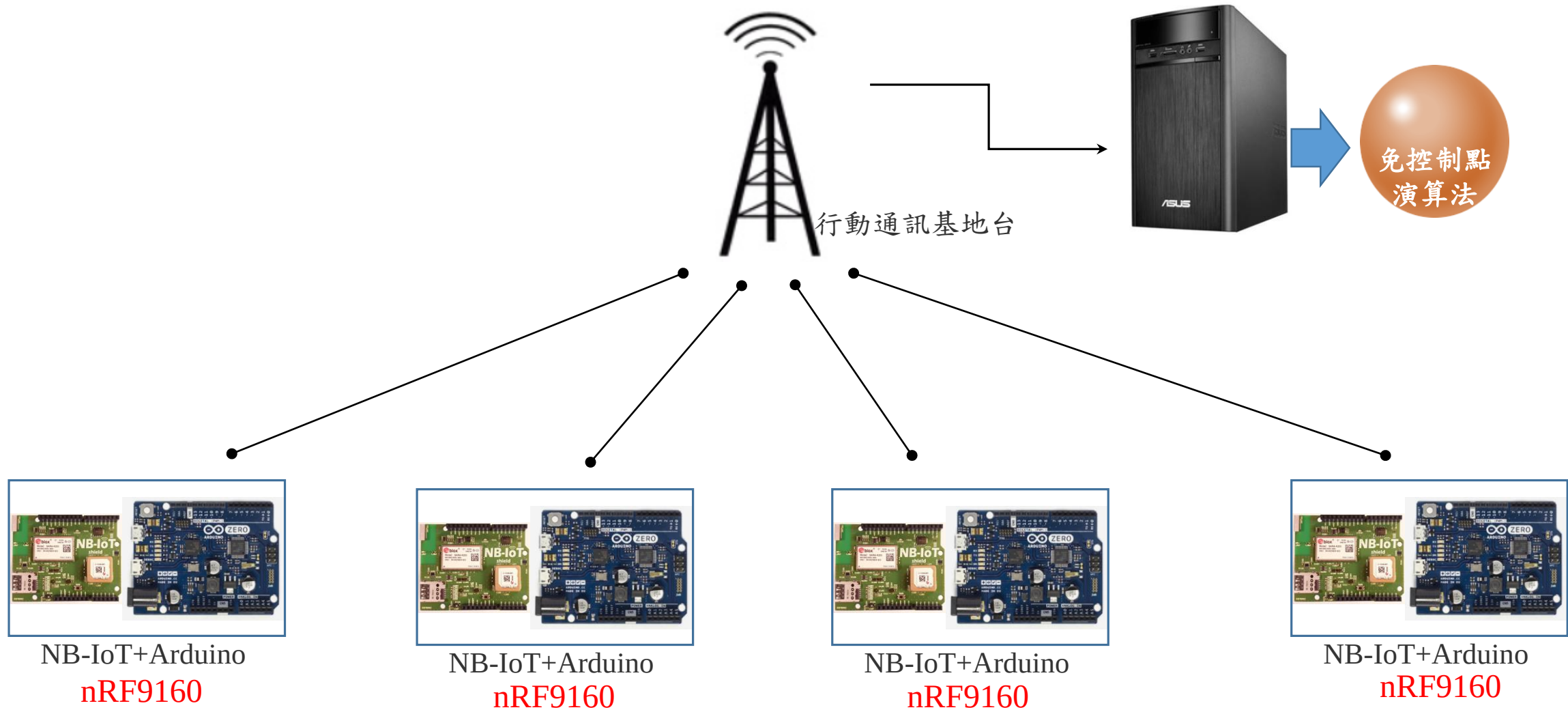
防砂壩機器學習分析(需求分析)

- 水位、雨量、水壓、溫度與位移量之收集
- 編寫機器學習程式碼
- 訓練與確認機器模式檢驗預測壩體位移之準確性

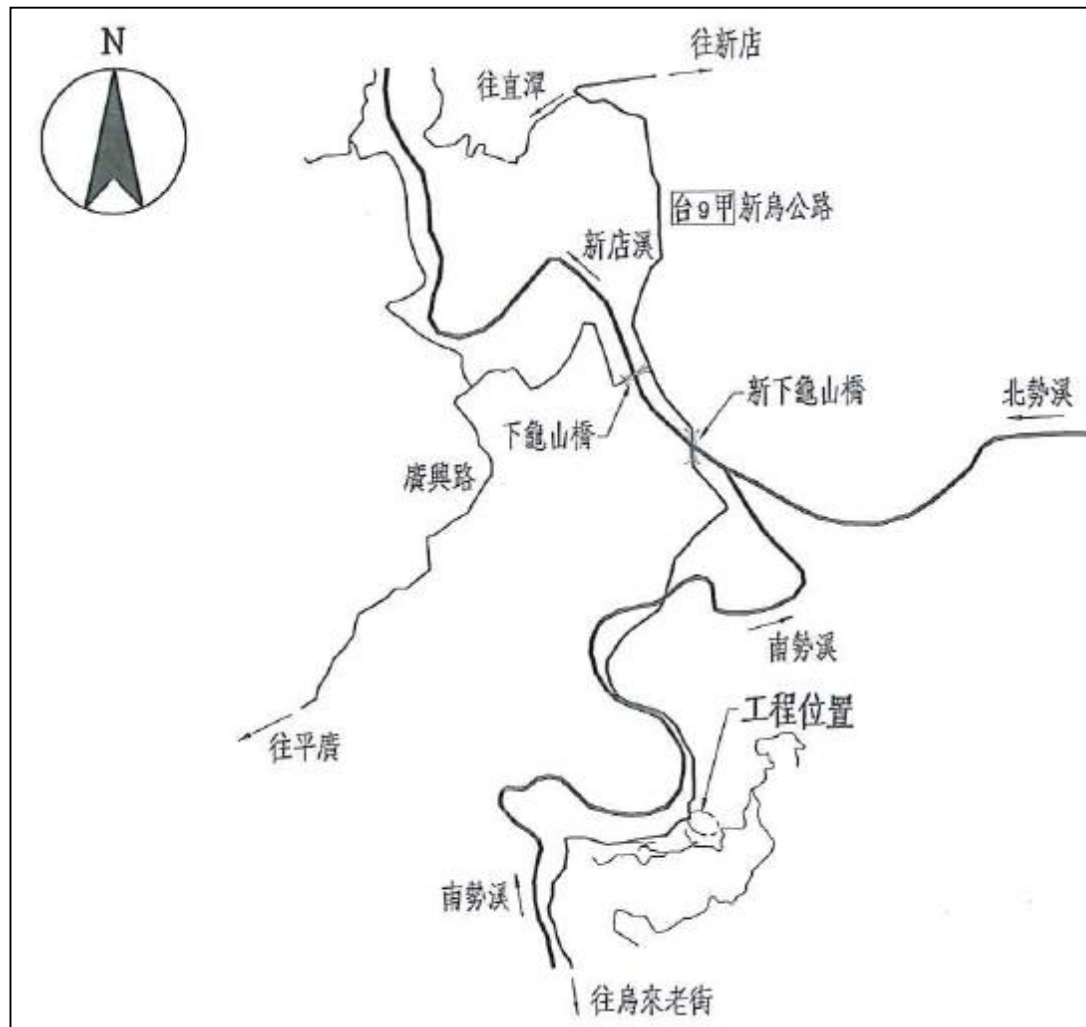


防砂壩系統識別分析(容量分析)

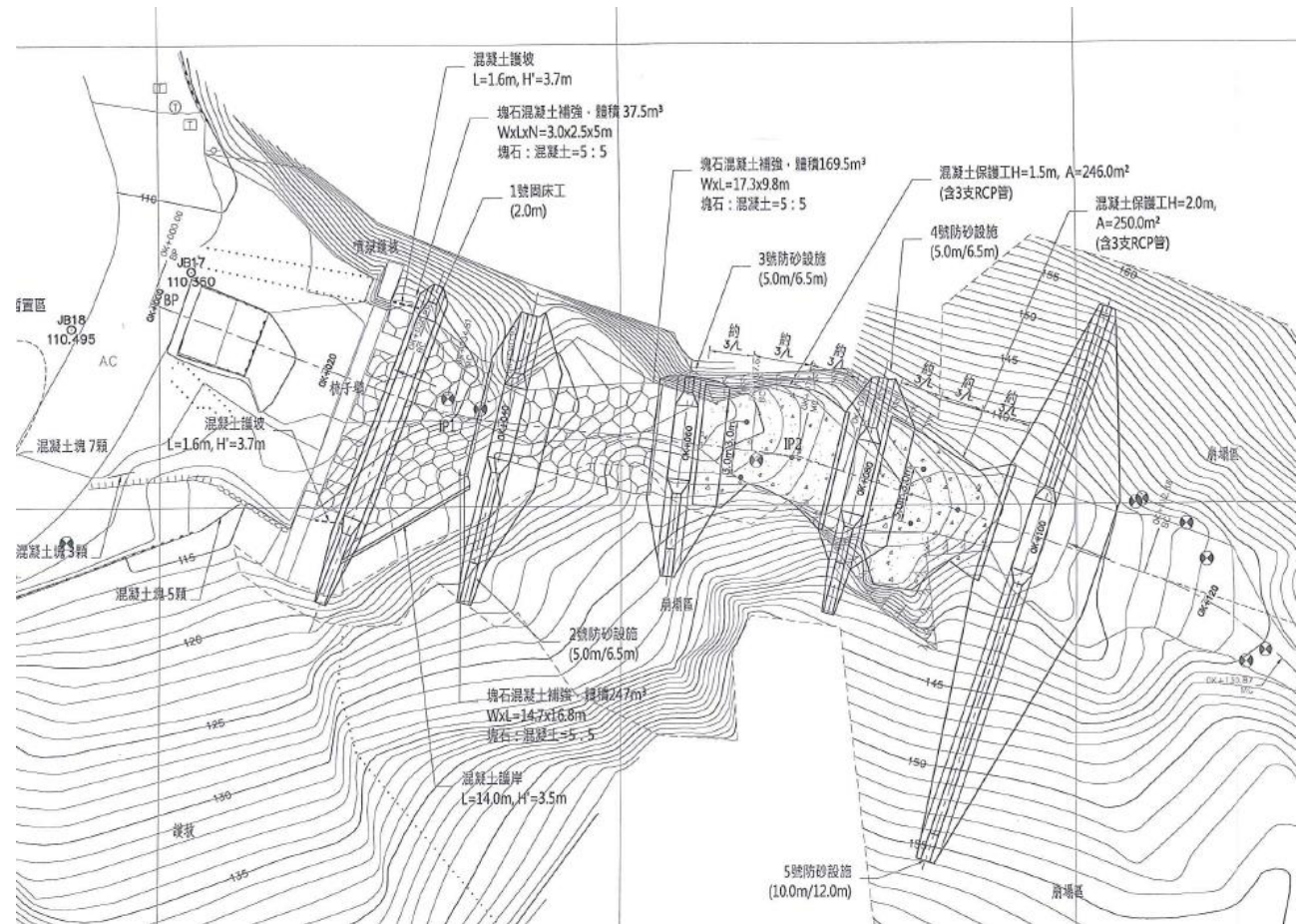
- 時域或頻域測量系統的輸入和輸出信號
- 確認壩體數值模型
- 以生物共生演算法推估模型參數



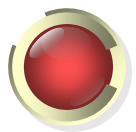
無線位移測量系統的示意圖



分析標的物之位置



分析標的物(5號壩)



利用加速度計量測加速度不需參考點，但須轉換為位移→ Proposed

$$\underset{u}{\text{Min}} \Pi_E(u) = \frac{1}{2} \int_{T_1}^{T_2} (a(u(t)) - \bar{a})^2 dt$$

$$\Pi_E(u) \approx \frac{1}{2} \left(\frac{1}{2} (a_1 - \bar{a}_1)^2 + (a_2 - \bar{a}_2)^2 + \dots + (a_{2k} - \bar{a}_{2k})^2 + \frac{1}{2} (a_{2k+1} - \bar{a}_{2k+1})^2 \right) \Delta t$$

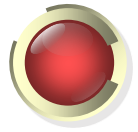
若使用中央差分近似 $a(u(t))$ ，則缺少兩個位移資訊(起點與終點)

$$\frac{u_{p+1} - 2u_p + u_{p-1}}{(\Delta t)^2} = a_p(u)$$



Newmark-beta method





利用加速度計量測加速度不需參考點，但須轉換為位移

$$\underset{u}{\text{Min}} \Pi_E(u) = \frac{1}{2} \int_{T_1}^{T_2} (a(u(t)) - \bar{a})^2 dt$$

$$\underset{u}{\text{Min}} \Pi(u) = \frac{1}{2} \|\mathbf{L}\mathbf{u} - (\Delta t)^2 \mathbf{L}_a \bar{\mathbf{a}}\|_2^2 + \frac{\lambda^2}{2} \|\mathbf{u}\|_2^2$$

$$u = (L^T L + \lambda^2 I)^{-1} L^T L_a \bar{a} (\Delta t)^2 = C \bar{a} (\Delta t)^2 \rightarrow \text{Tikhonov 正則化}$$

緩和 ill-posedness

$$\lambda = 46.81 N_d^{-1.95} \quad N_d = f_s \frac{N_w}{f_T}$$

Moore-Penrose pseudo inverse

免控制點演算法之開發

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粒子群演算法

$$\text{Min}_u \Pi(u) = \frac{1}{2} \|\mathbf{L}\mathbf{u} - (\Delta t)^2 \mathbf{L}_a \bar{\mathbf{a}}\|_2^2 + \frac{\lambda^2}{2} \|\mathbf{u}\|_2^2$$

$$\mathbf{u} = \left(\mathbf{L}^T \mathbf{L} + \lambda^2 \mathbf{I} \right)^{-1} \mathbf{L}^T \mathbf{L}_a \bar{\mathbf{a}} (\Delta t)^2$$

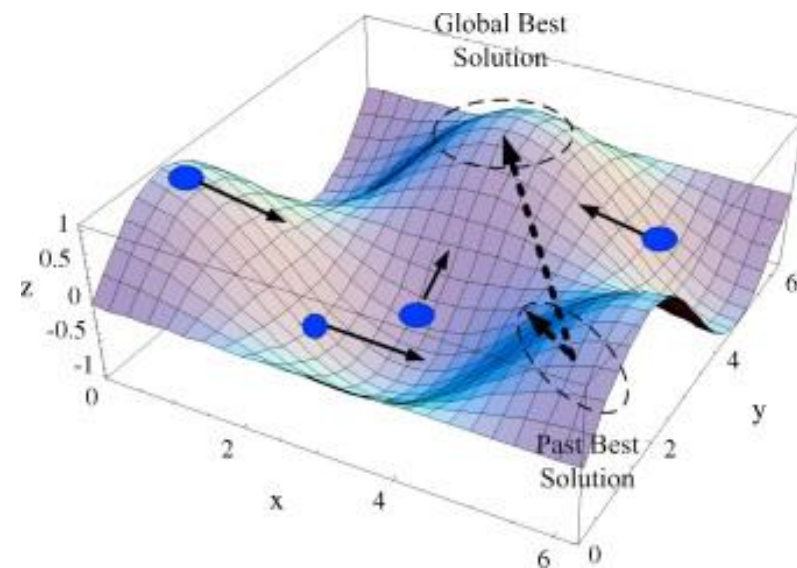
$$\lambda = 46.81 N_d^{-1.95}$$

$$\lambda = 5.5922 \Delta t^{2.1144} \times f_T^{-608.67 \Delta t^2 + 6.97 \Delta t + 1.8054}$$

$$N_d = f_s \frac{N_w}{f_T} \longrightarrow N_d = 28.845 \Delta t^{0.5}$$



Source: TurningFinance



Source: Mathworks

免控制點演算法之開發

$$\text{Min}(u) = 0.5 \left\| Lu - (\Delta t)^2 L_a \bar{a} \right\|_2^2 + \frac{\lambda^2}{2} \|u\|_2^2$$

Interval Time	0.02								
Target frequency	PSO 1		Author		Proposed		RMS from PSO 1	RMS Author	RMS Proposed
	N_d	λ	N_d	λ	N_d	λ			
1	416	0.001432	150	2.67E-03	204	2.24E-03	0.00150	0.00220	0.00174
1.2	274	0.001889	125	3.81E-03	204	3.05E-03	0.00130	0.00180	0.00140
1.4	328	0.002847	107	5.16E-03	204	3.96E-03	0.00110	0.00150	0.00118
1.6	418	0.003727	94	6.65E-03	204	4.97E-03	0.00090	0.00120	0.00100
1.8	423	0.004703	83	8.47E-03	204	6.07E-03	0.00080	0.00110	0.00088
2	438	0.005791	75	1.03E-02	204	7.26E-03	0.00070	0.00090	0.00075
2.2	172	0.006785	68	1.25E-02	204	8.54E-03	0.00060	0.00090	0.00068
2.4	109	0.007594	62	1.50E-02	204	9.89E-03	0.00050	0.00070	0.00060
2.6	109	0.008321	58	1.70E-02	204	1.13E-02	0.00050	0.00070	0.00055
2.8	105	0.009796	54	1.96E-02	204	1.29E-02	0.00040	0.00060	0.00051
3	132	0.010535	50	2.28E-02	204	1.44E-02	0.00040	0.00060	0.00047
3.2	133	0.011515	47	2.57E-02	204	1.61E-02	0.00040	0.00050	0.00044
9	347	0.070816	17	1.87E-01	204	9.32E-02	0.00010	0.00010	0.00011
9.2	47	0.074045	16	2.10E-01	204	9.67E-02	0.00010	0.00010	0.00011
9.4	45	0.079282	16	2.10E-01	204	1.00E-01	0.00010	0.00010	0.00010
9.6	288	0.083827	16	2.10E-01	204	1.04E-01	0.00010	0.00010	0.00010
9.8	429	0.088607	15	2.38E-01	204	1.08E-01	0.00010	0.00010	0.00010
10	41	0.093893	15	2.38E-01	204	1.11E-01	0.00010	0.00010	0.00009
Average RMS							3.20E-04	4.39E-04	3.70E-04
Max RMS							1.50E-03	2.20E-03	1.74E-03
Min RMS							1.00E-04	1.00E-04	9.42E-05

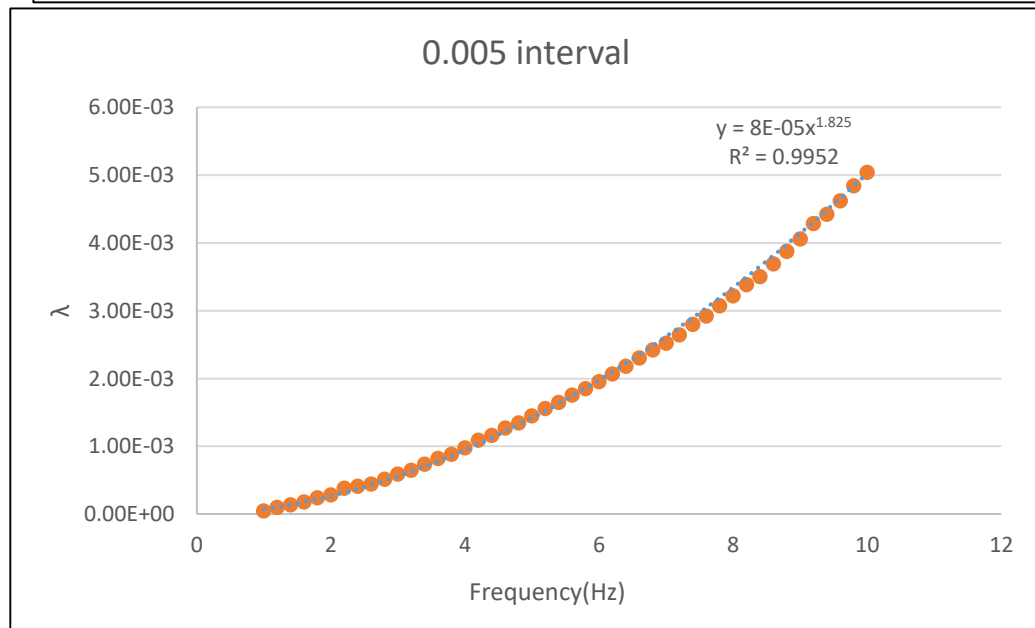
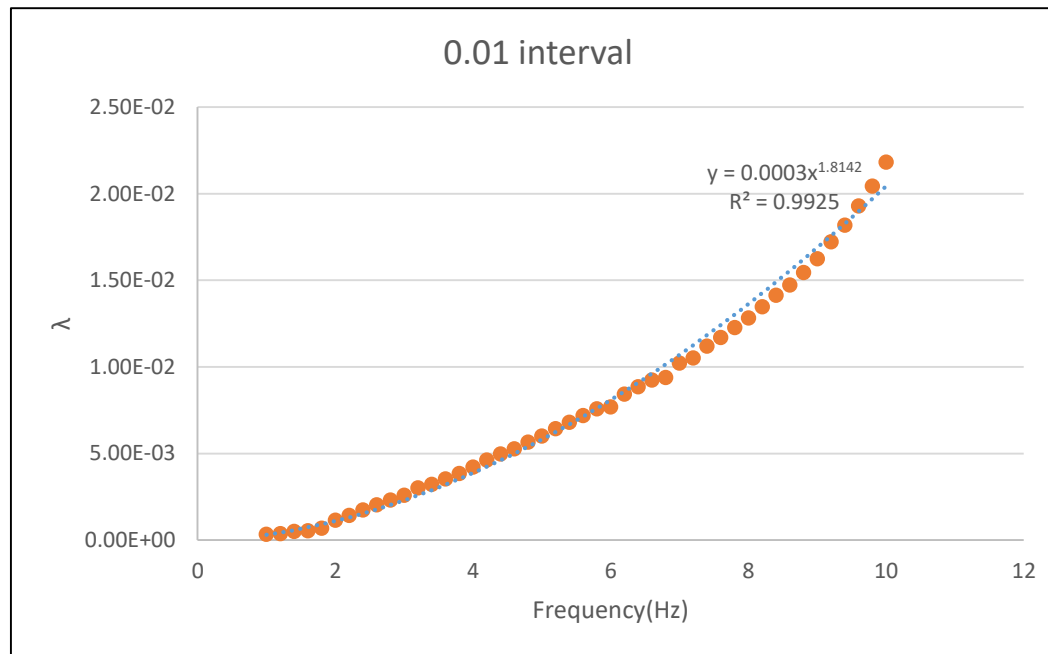
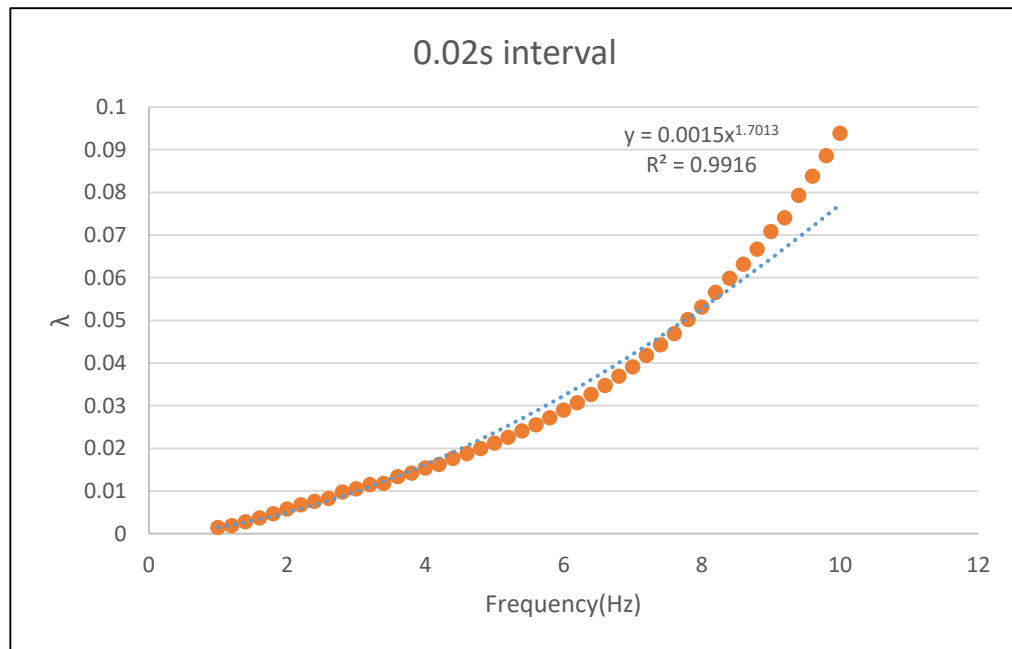
$$\text{Min}(u) = 0.5 \left\| Lu - (\Delta t)^2 L_a \bar{a} \right\|_2^2 + \frac{\lambda^2}{2} \|u\|_2^2$$

Interval Time	0.01								
Target frequency	PSO 1		Author		Proposed		RMS from PSO 1	RMS Author	RMS Proposed
	N _d	λ	N _d	λ	N _d	λ			
1	476	3.38E-04	300	6.92E-04	288	5.60E-04	0.00020	0.00230	0.00206
1.2	500	3.79E-04	250	9.87E-04	288	7.79E-04	0.00020	0.00180	0.00198
1.4	485	4.94E-04	214	1.34E-03	288	1.03E-03	0.00020	0.00160	0.00121
1.6	497	0.000539	188	1.72E-03	288	1.31E-03	0.00020	0.00120	0.00098
1.8	481	0.000695	167	2.17E-03	288	1.62E-03	0.00020	0.00110	0.00088
2	348	0.001155	150	2.67E-03	288	1.96E-03	0.00020	0.00100	0.00074
2.2	317	0.001429	136	3.24E-03	288	2.33E-03	0.00020	0.00090	0.00067
2.4	289	0.001735	125	3.81E-03	288	2.73E-03	0.00020	0.00070	0.00060
2.6	353	0.002038	115	4.49E-03	288	3.15E-03	0.00020	0.00070	0.00054
2.8	347	0.00231	107	5.16E-03	288	3.61E-03	0.00020	0.00060	0.00049
3	272	0.002593	100	5.89E-03	288	4.09E-03	0.00010	0.00060	0.00045
3.2	268	0.003013	94	6.65E-03	288	4.59E-03	0.00010	0.00050	0.00042
9	178	0.01625	33	5.12E-02	288	2.98E-02	0.00003	0.00010	0.00011
9.2	162	0.017226	33	5.12E-02	288	3.10E-02	0.00003	0.00010	0.00010
9.4	379	0.018176	32	5.44E-02	288	3.23E-02	0.00003	0.00010	0.00010
9.6	160	0.019298	31	5.78E-02	288	3.35E-02	0.00002	0.00010	0.00010
9.8	350	0.020433	31	5.78E-02	288	3.48E-02	0.00002	0.00010	0.00009
10	155	0.02182	30	6.17E-02	288	3.61E-02	0.00002	0.00010	0.00009
Average RMS							1.02E-04	4.48E-04	3.81E-04
Max RMS							2.00E-04	2.30E-03	2.06E-03
Min RMS							2.21E-05	1.00E-04	9.12E-05

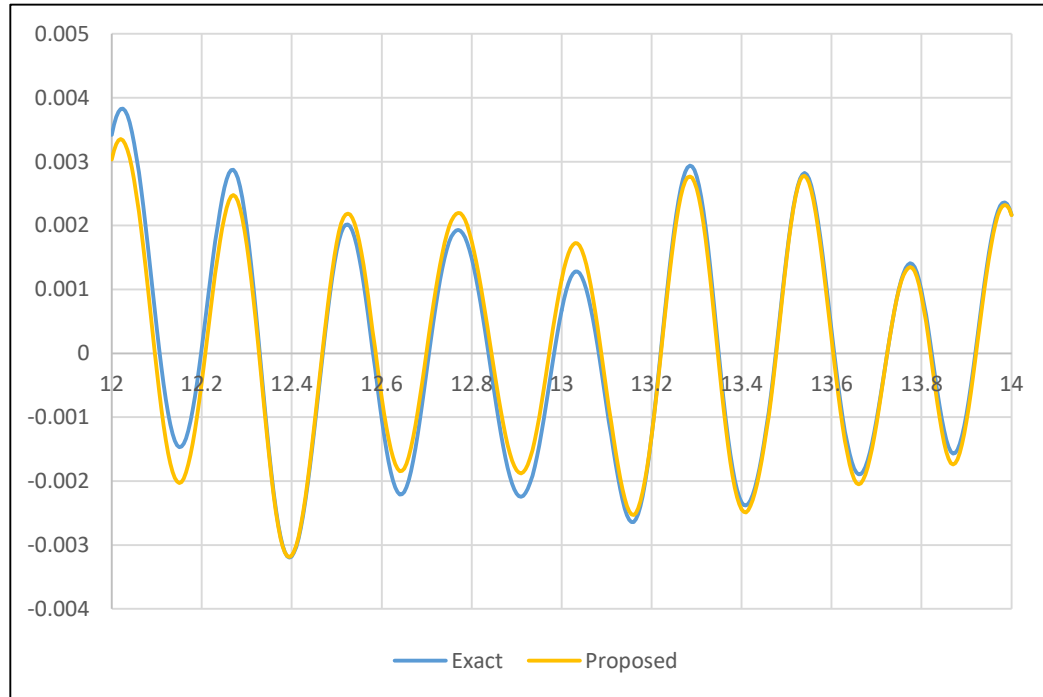
免控制點演算法之開發

$$\text{Min}(u) = 0.5 \left\| Lu - (\Delta t)^2 L_a \bar{a} \right\|_2^2 + \frac{\lambda^2}{2} \|u\|_2^2$$

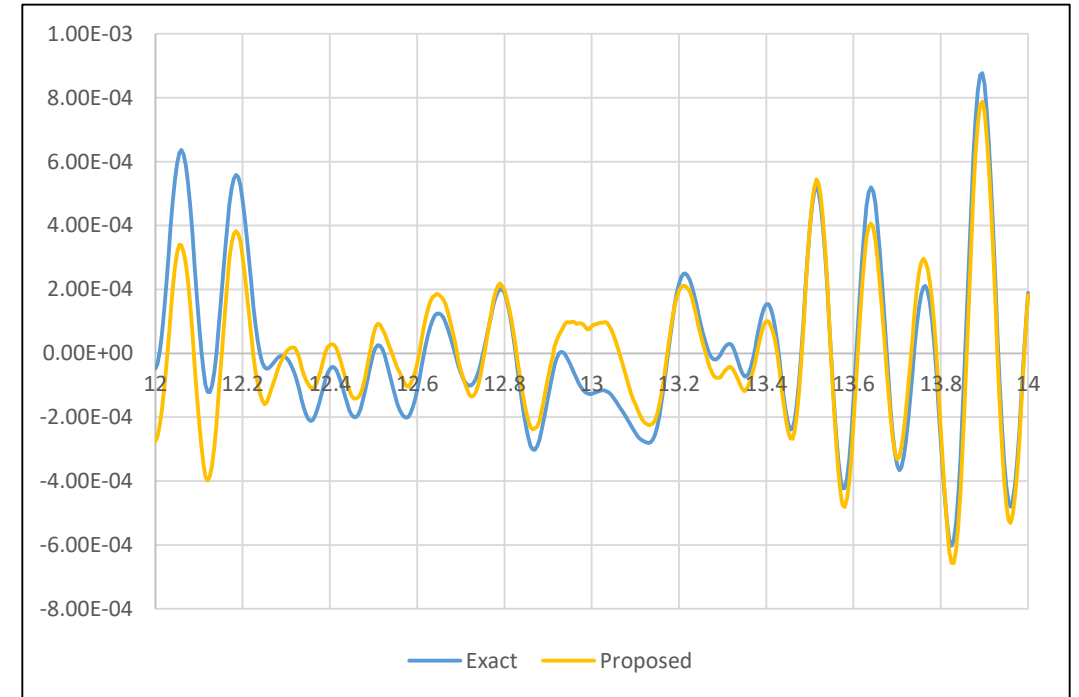
Interval Time	0.005								
Target frequency	PSO 1		Author		Proposed		RMS from PSO 1	RMS from Author	RMS Proposed
	N_d	λ	N_d	λ	N_d	λ			
1	397	4.97E-05	600	1.79E-04	408	1.40E-04	0.00020	0.00220	0.00199
1.2	370	9.90E-05	500	2.55E-04	408	1.95E-04	0.00020	0.00180	0.00182
1.4	379	0.000136	429	3.44E-04	408	2.58E-04	0.00020	0.00160	0.00139
1.6	312	1.78E-04	375	4.48E-04	408	3.29E-04	0.00020	0.00120	0.00121
1.8	288	2.43E-04	333	5.64E-04	408	4.08E-04	0.00020	0.00110	0.00098
2	269	0.000285	300	6.92E-04	408	4.94E-04	0.00020	0.00100	0.00075
2.2	446	0.000383	273	8.31E-04	408	5.88E-04	0.00020	0.00090	0.00065
2.4	500	0.000411	250	9.87E-04	408	6.89E-04	0.00020	0.00080	0.00058
2.6	453	0.000445	231	1.15E-03	408	7.97E-04	0.00020	0.00070	0.00052
2.8	441	0.000515	214	1.34E-03	408	9.12E-04	0.00010	0.00060	0.00048
3	438	0.000589	200	1.53E-03	408	1.03E-03	0.00010	0.00060	0.00044
3.2	426	0.000646	188	1.72E-03	408	1.16E-03	0.00010	0.00050	0.00041
9	430	0.004063	67	1.29E-02	408	7.63E-03	0.00003	0.00010	0.00010
9.2	423	0.004286	65	1.37E-02	408	7.94E-03	0.00003	0.00010	0.00010
9.4	335	0.004427	64	1.41E-02	408	8.26E-03	0.00003	0.00010	0.00010
9.6	298	0.004623	63	1.45E-02	408	8.58E-03	0.00002	0.00010	0.00009
9.8	333	0.004846	61	1.55E-02	408	8.91E-03	0.00002	0.00010	0.00009
10	325	0.005043	60	1.60E-02	408	9.25E-03	0.00002	0.00010	0.00009
Average RMS							9.58E-05	4.46E-04	3.78E-04
Max RMS							2.00E-04	2.20E-03	1.99E-03
Min RMS							2.14E-05	1.00E-04	8.63E-05



$$\lambda = 5.5922\Delta t^{2.1144} \times f_T^{-608.67\Delta t^2 + 6.97\Delta t + 1.8054}$$



Proposed and Exact displacement of 4Hz



Proposed and Exact displacement of 8Hz

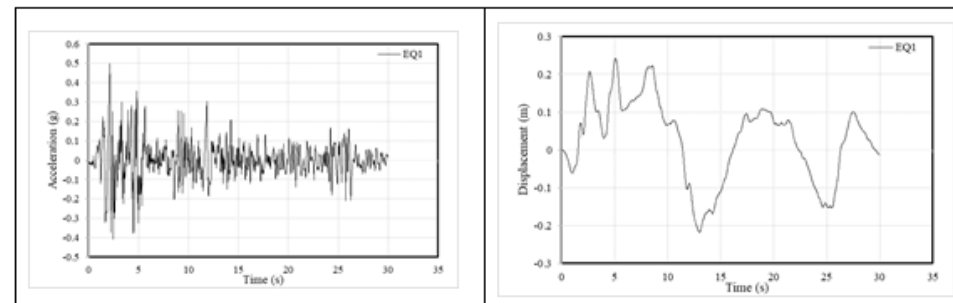
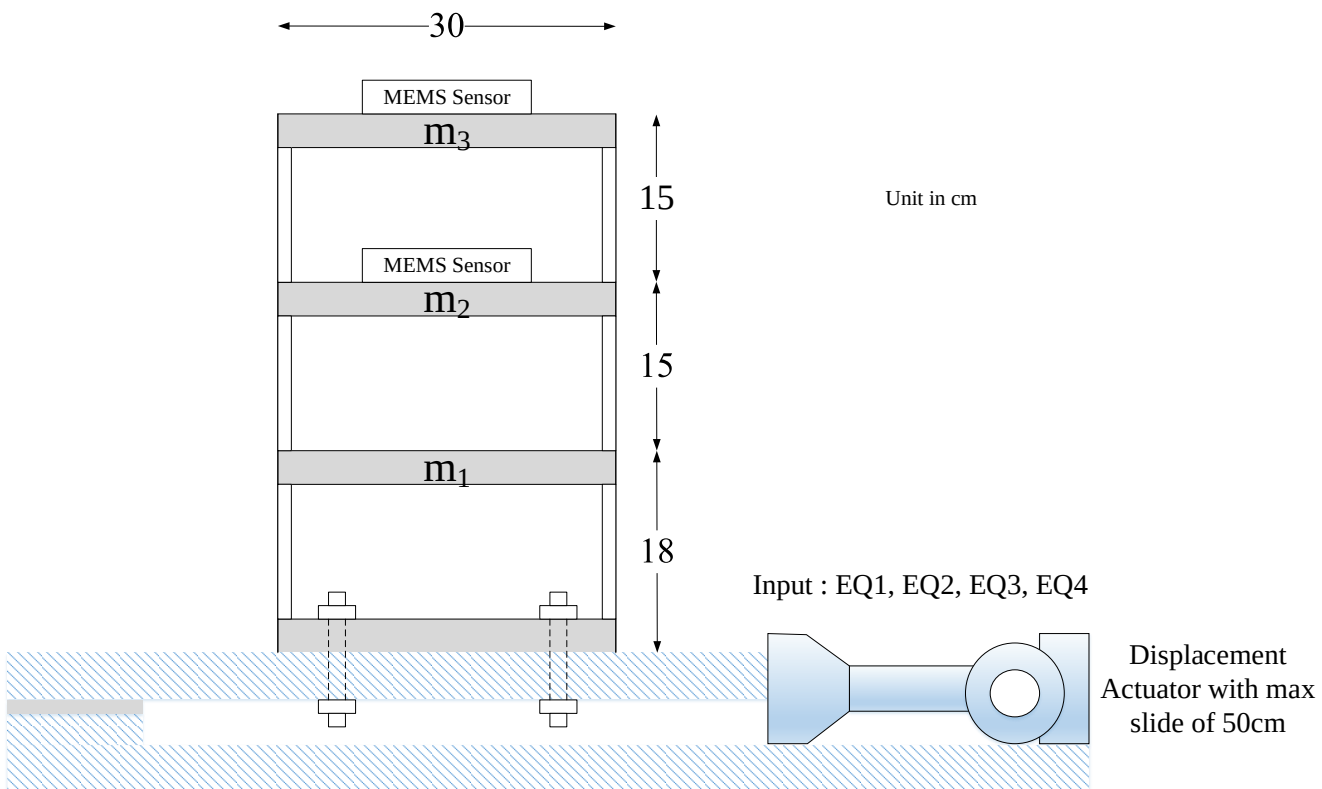
重建位移之驗證-室內縮尺度



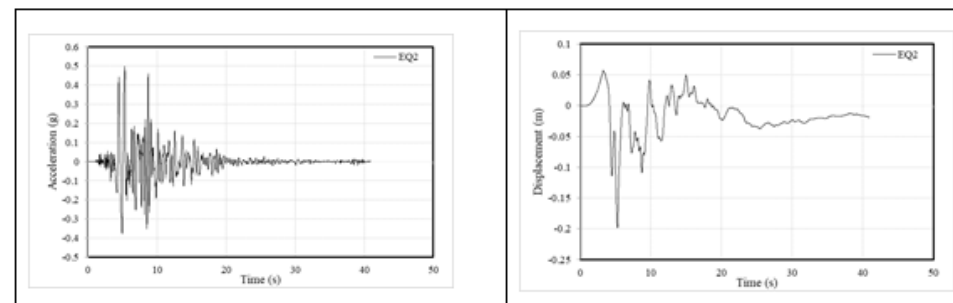
大樓模型



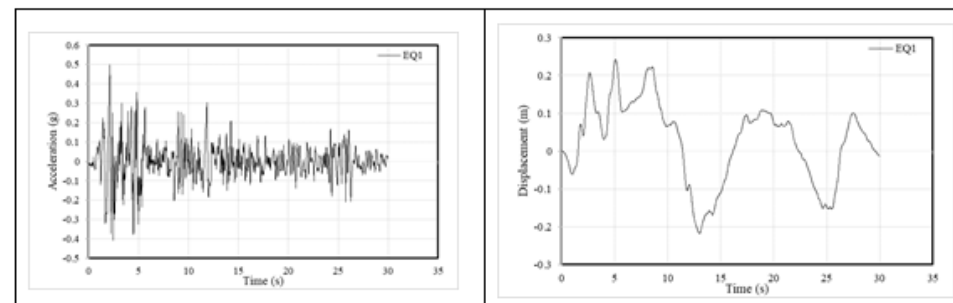
振動臺



試驗地表加速度與位移歷時(EQ1)



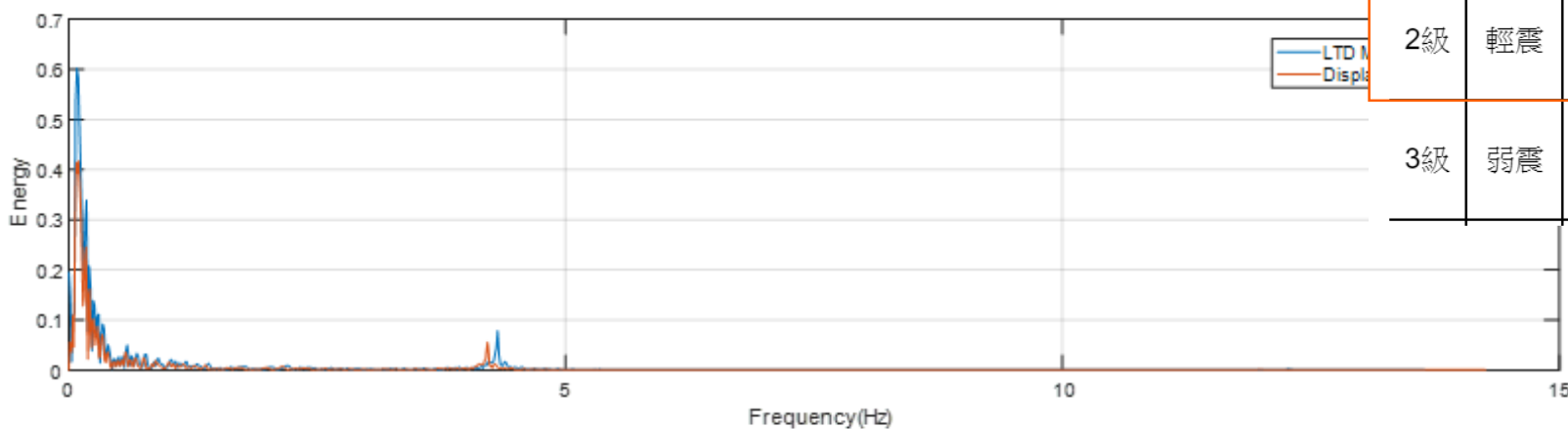
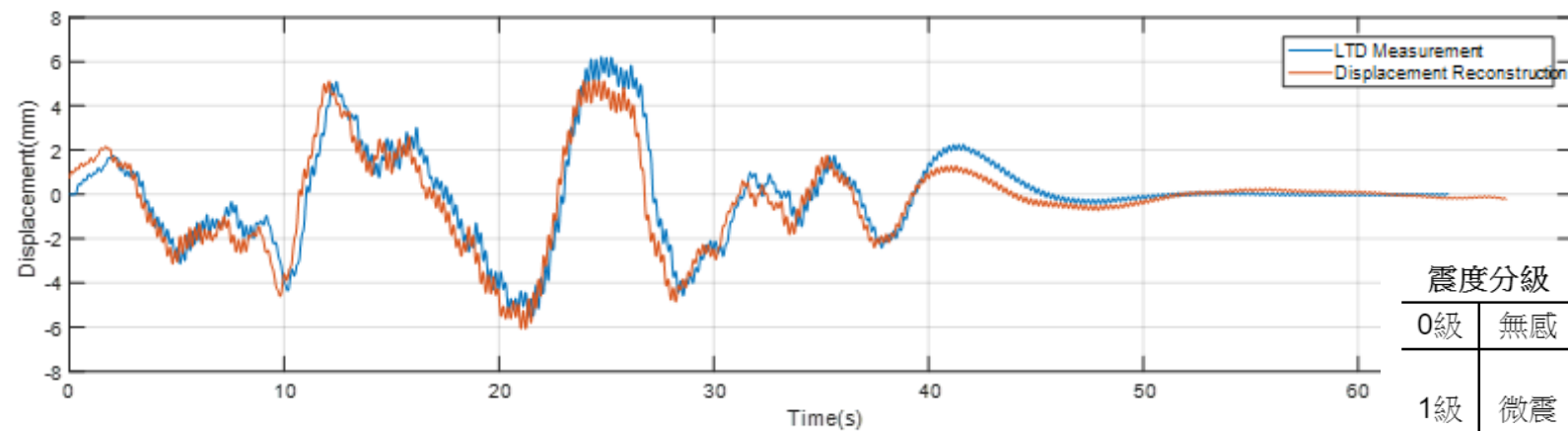
試驗地表加速度與位移歷時(EQ2)



試驗地表加速度與位移歷時(EQ3)

試驗之設定

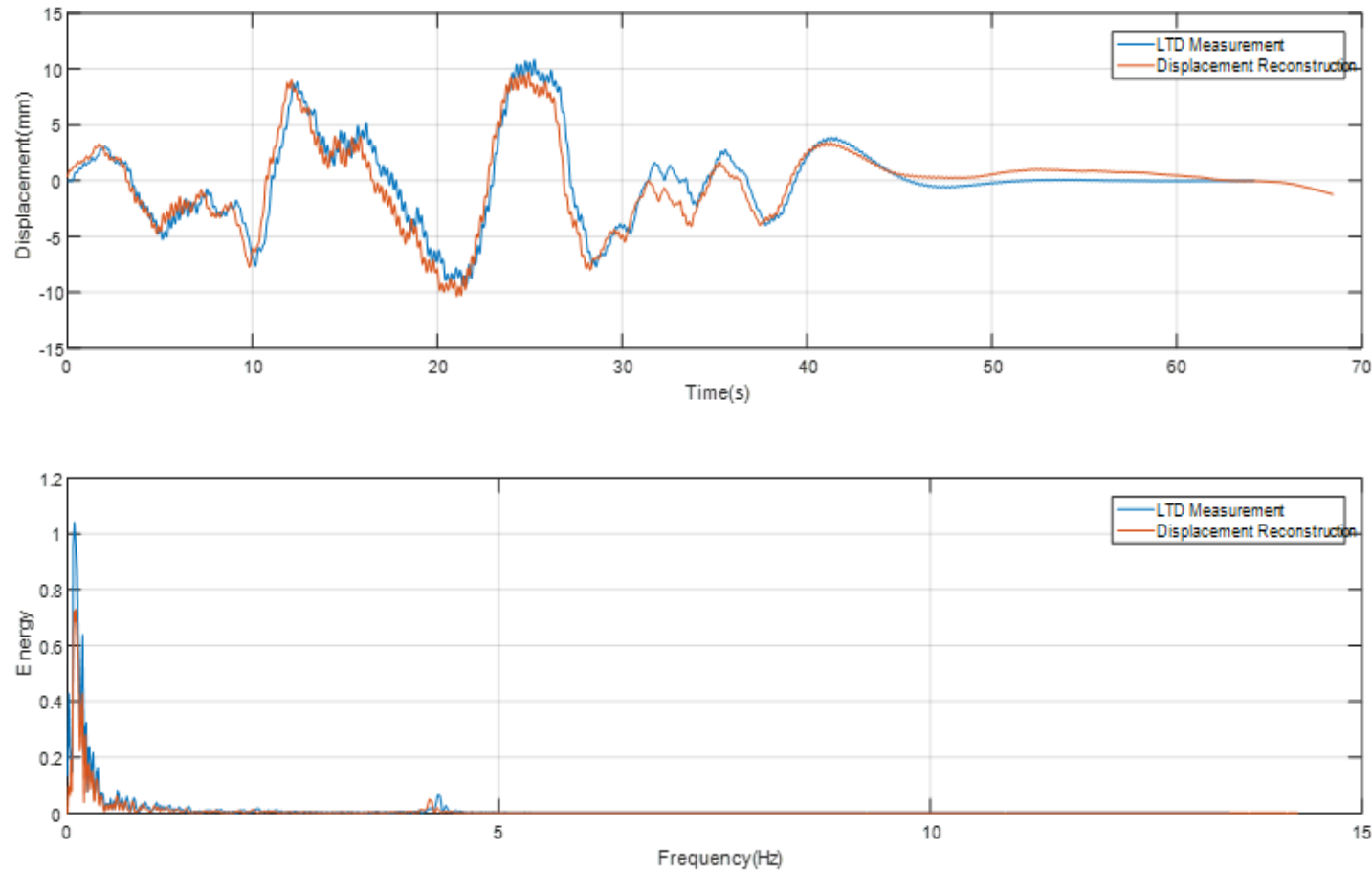
Results of experiments at NCREE



震度分級		人的感受	屋內情形	屋外情形
0級	無感	人無感覺		
1級	微震	人靜止或位於高樓層時可感覺微小搖晃		
2級	輕震	大多數的人可感到搖晃，睡眠中的人有部分會醒來	電燈等懸掛物有小搖晃	靜止的汽車輕輕搖晃，類似卡車經過，但歷時很短
3級	弱震	幾乎所有的人都感覺搖晃，有的人會有恐懼感	房屋震動，碗盤門窗發出聲音，懸掛物搖擺	靜止的汽車明顯搖動，電線略有搖晃

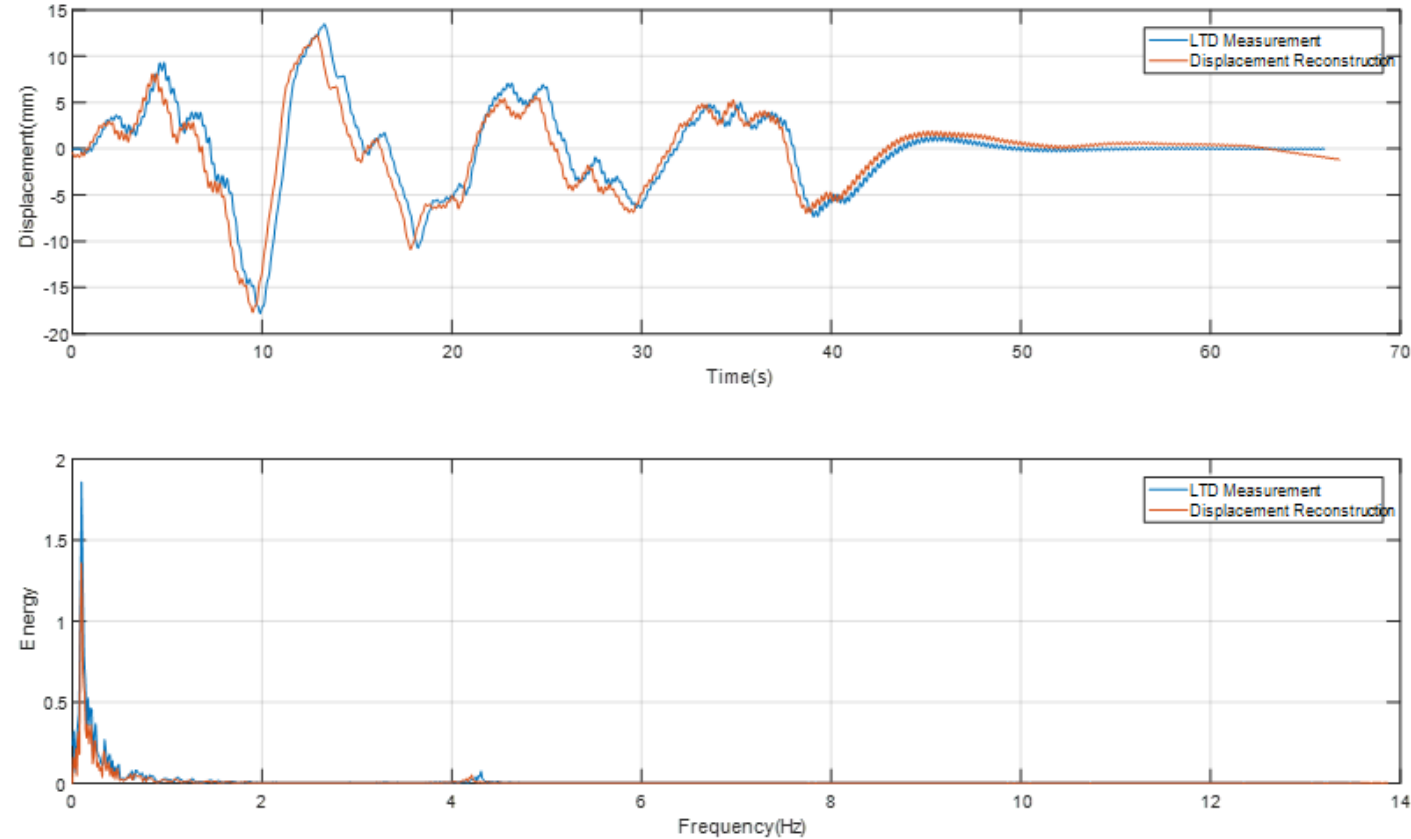
EQ1-No Mass-Relative Displacement with PGA 0.008g

Results of experiments at NCREE



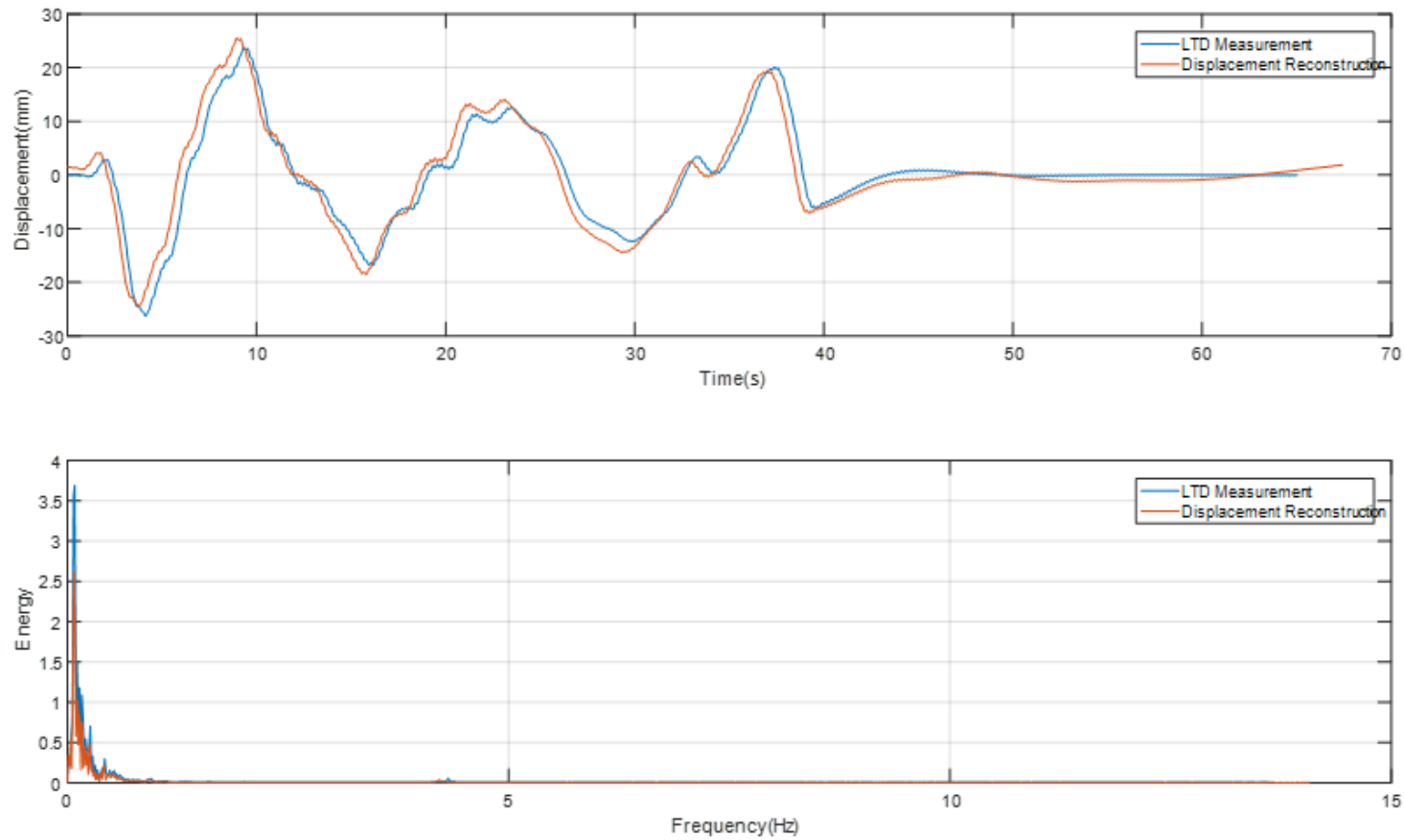
EQ1-No Mass-Relative Displacement with PGA 0.014g

Results of experiments at NCREE



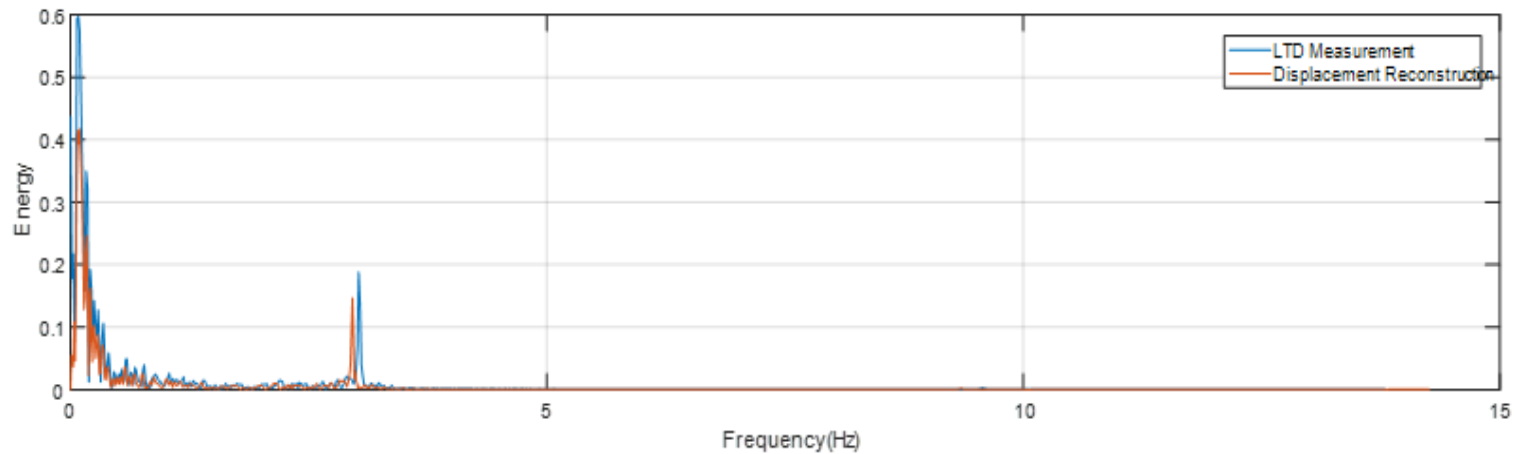
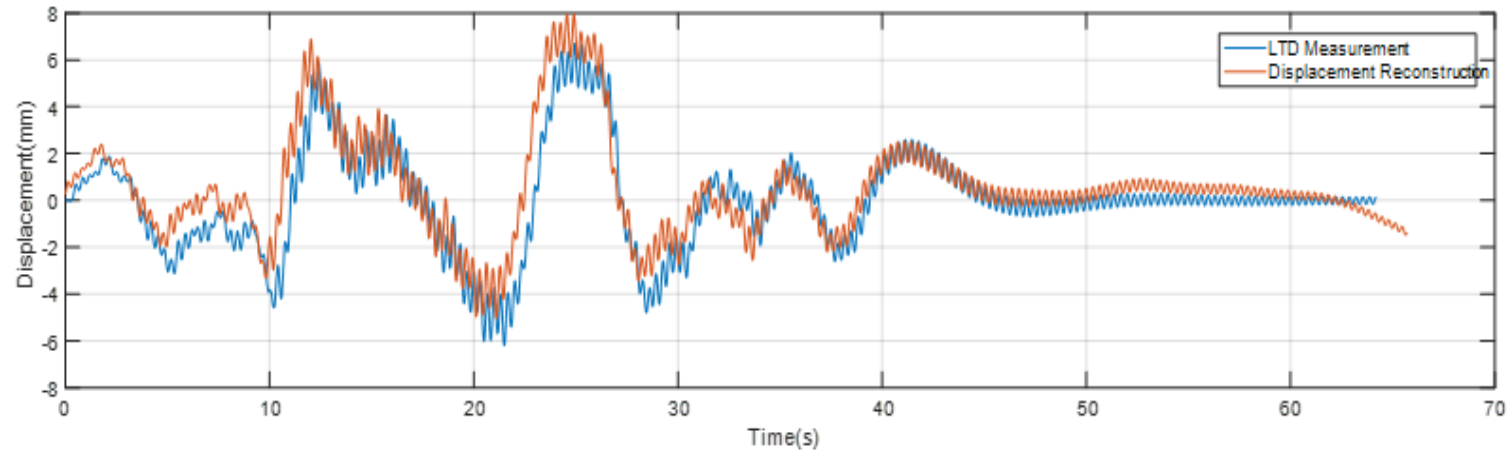
EQ2-No Mass-Relative Displacement with PGA 0.008g

Results of experiments at NCREE

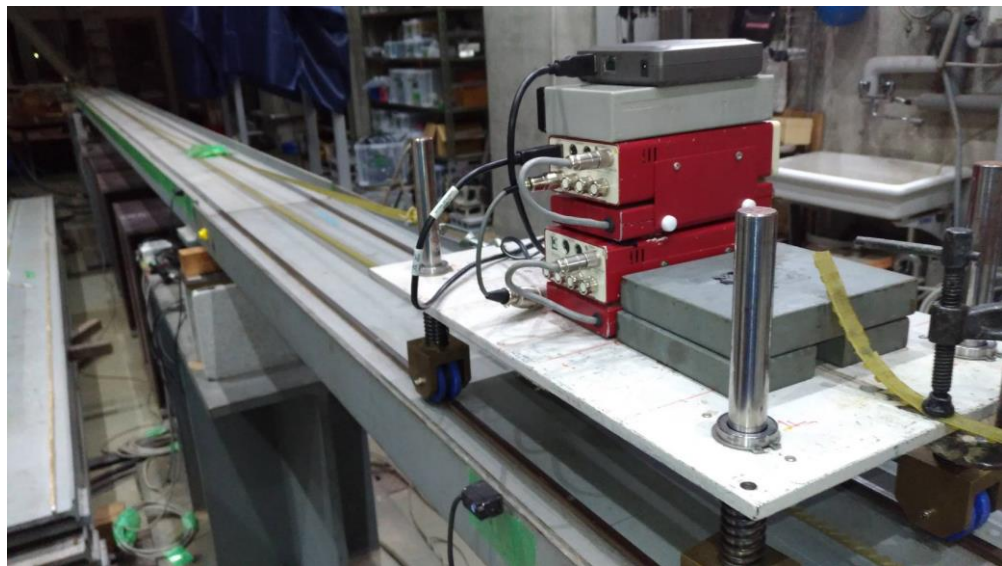


EQ3-No Mass-Relative Displacement with PGA 0.008g

Results of experiments at NCREE

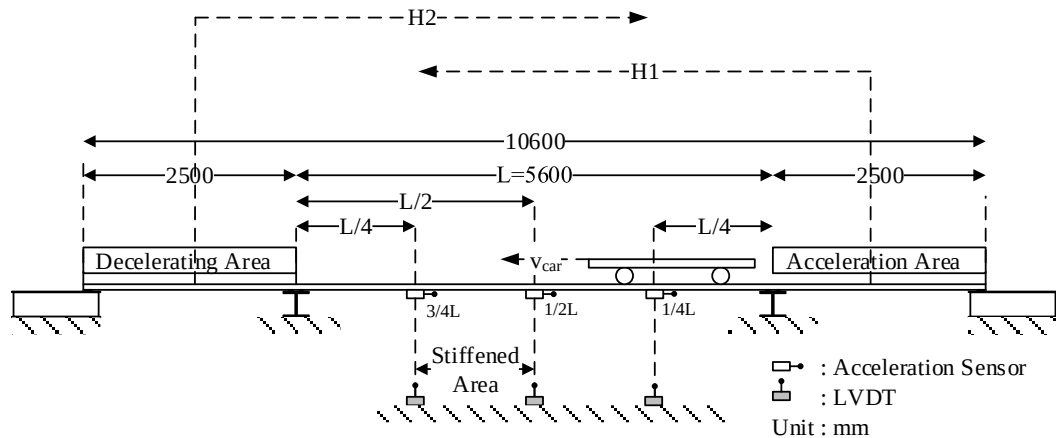


EQ1- with Mass-Relative Displacement with PGA 0.008g



京都大學縮尺橋梁模型

京都大學縮尺橋梁試驗設定



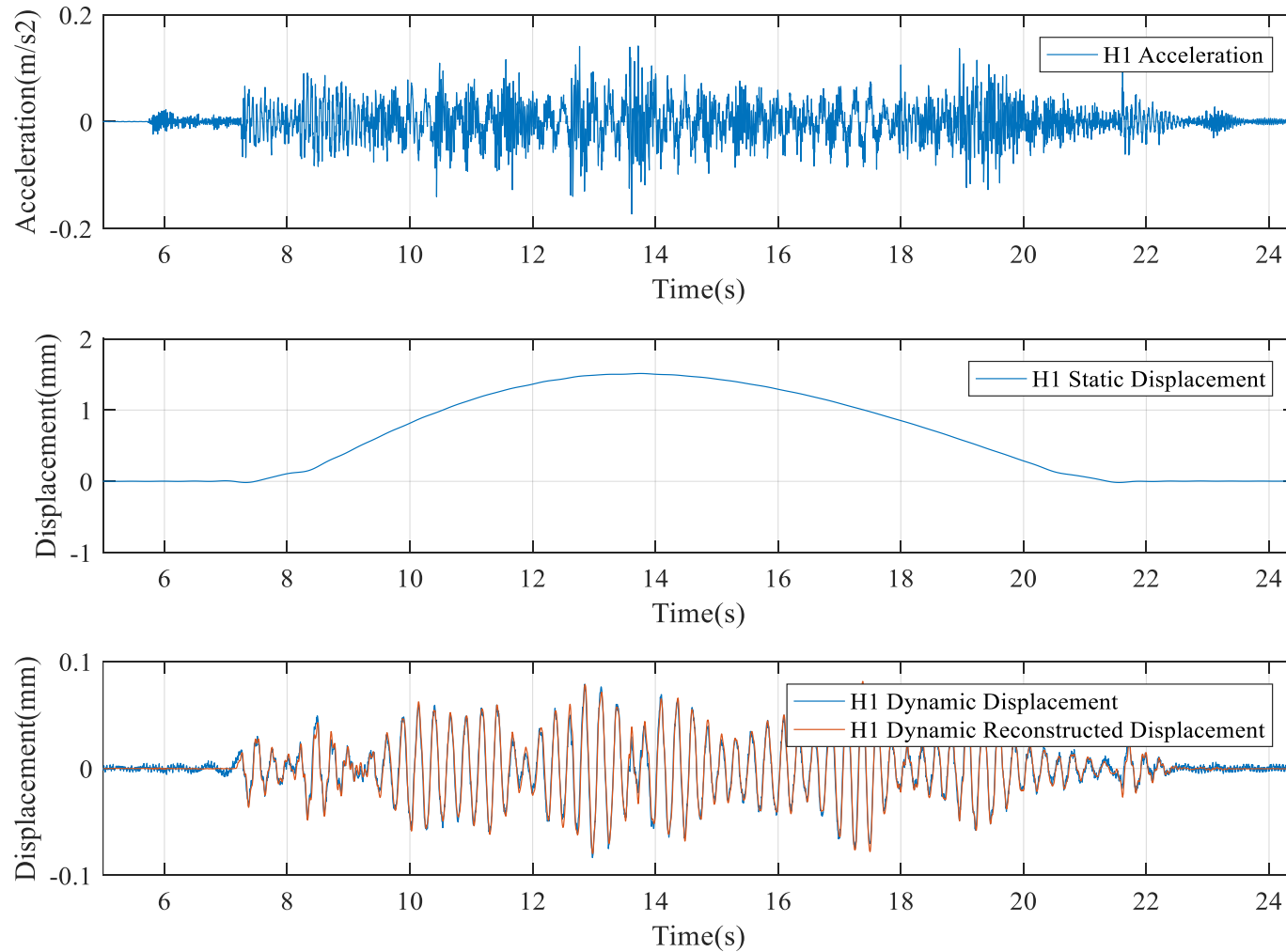
No	Scenario Name	Vehicle	Bridge Type	Vehicle Mass	Vehicle Speed (m/s)
1	LV1B0S1	Tractor	Original	Light	0.4
2	LV1B0S2	Tractor	Original	Light	0.8
3	LV1B0S3	Tractor	Original	Light	1.2
4	HV1B0S1	Tractor	Original	Heavy	0.4
5	HV1B0S2	Tractor	Original	Heavy	0.8
6	HV1B0S3	Tractor	Original	Heavy	1.2
7	LV1B1S1	Tractor	Stiffened	Light	0.4
8	LV1B1S2	Tractor	Stiffened	Light	0.8
9	LV1B1S3	Tractor	Stiffened	Light	1.2
10	HV1B1S1	Tractor	Stiffened	Heavy	0.4
11	HV1B1S2	Tractor	Stiffened	Heavy	0.8
12	HV1B1S3	Tractor	Stiffened	Heavy	1.2
13	LV2B0S1	Trailer	Original	Light	0.4
14	LV2B0S2	Trailer	Original	Light	0.8
15	LV2B0S3	Trailer	Original	Light	1.2
16	HV2B0S1	Trailer	Original	Heavy	0.4
17	HV2B0S2	Trailer	Original	Heavy	0.8
18	HV2B0S3	Trailer	Original	Heavy	1.2
19	LV2B1S1	Trailer	Stiffened	Light	0.4
20	LV2B1S2	Trailer	Stiffened	Light	0.8
21	LV2B1S3	Trailer	Stiffened	Light	1.2
22	HV2B1S1	Trailer	Stiffened	Heavy	0.4
23	HV2B1S2	Trailer	Stiffened	Heavy	0.8
24	HV2B1S3	Trailer	Stiffened	Heavy	1.2

Original Bridge				
Mode	Frequency Mode Statistical Properties (Hz)			
	Max	Min	Mean	c.o.v
1	3.733	3.733	3.733	0.000
2	15.067	14.933	14.987	0.005
3	32.000	29.600	30.800	0.037

Stiffened Bridge				
Mode	Frequency Mode Statistical Properties (Hz)			
	Max	Min	Mean	c.o.v
1	3.867	3.867	3.867	0.000
2	14.533	14.533	14.533	0.000
3	31.867	30.667	31.493	0.015

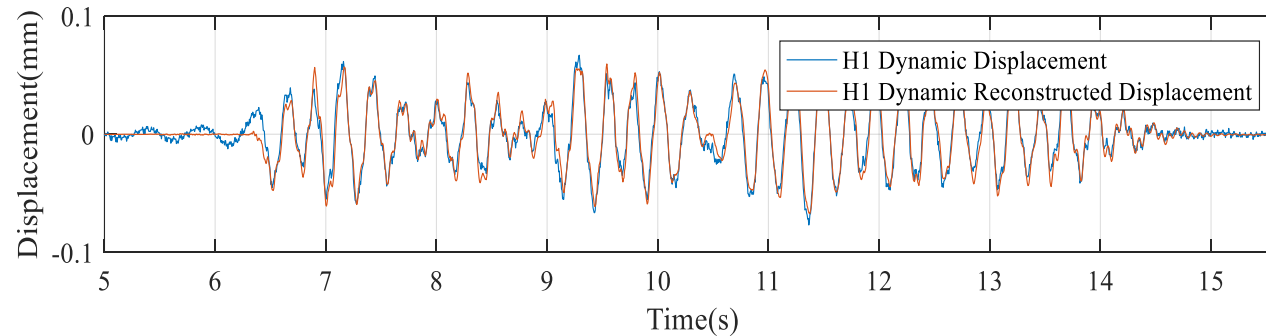
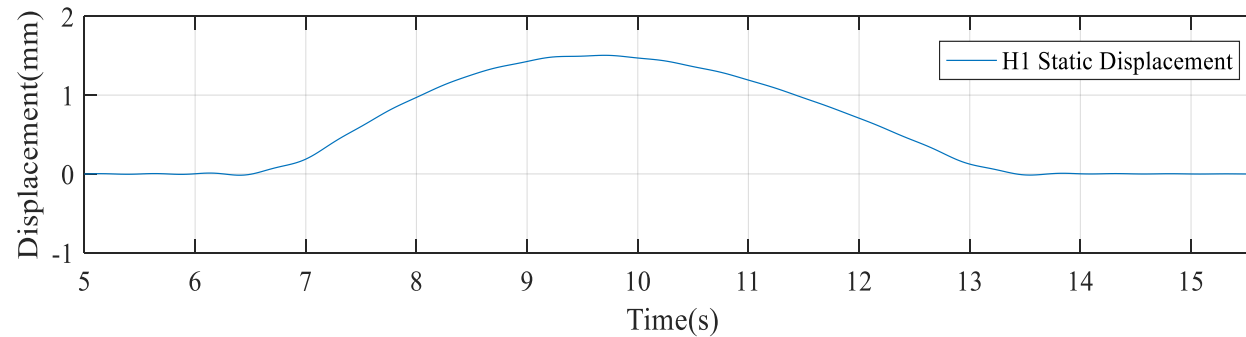
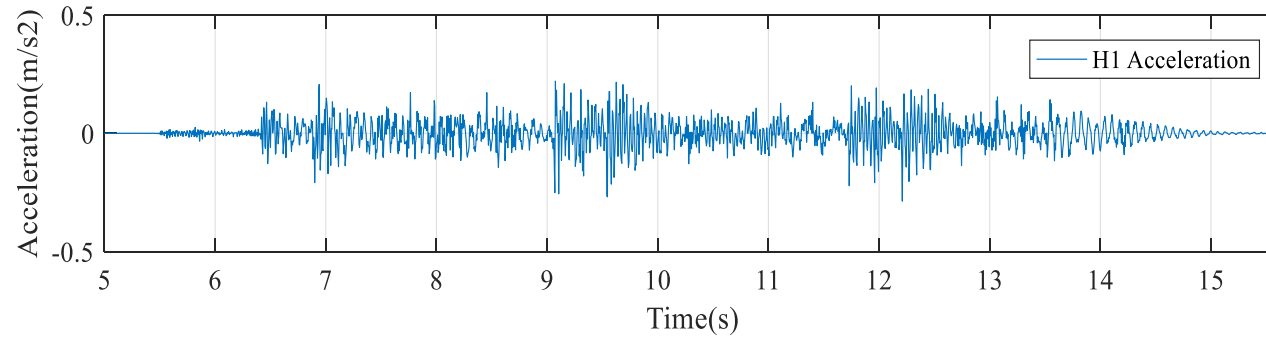
Bridge	First Mode Damping Ratio Statistical Properties			
	Max	Min	Mean	c.o.v
Original	0.025	0.019	0.023	0.114
Stiffened	0.018	0.016	0.017	0.047

Results of experiments at Kyoto University



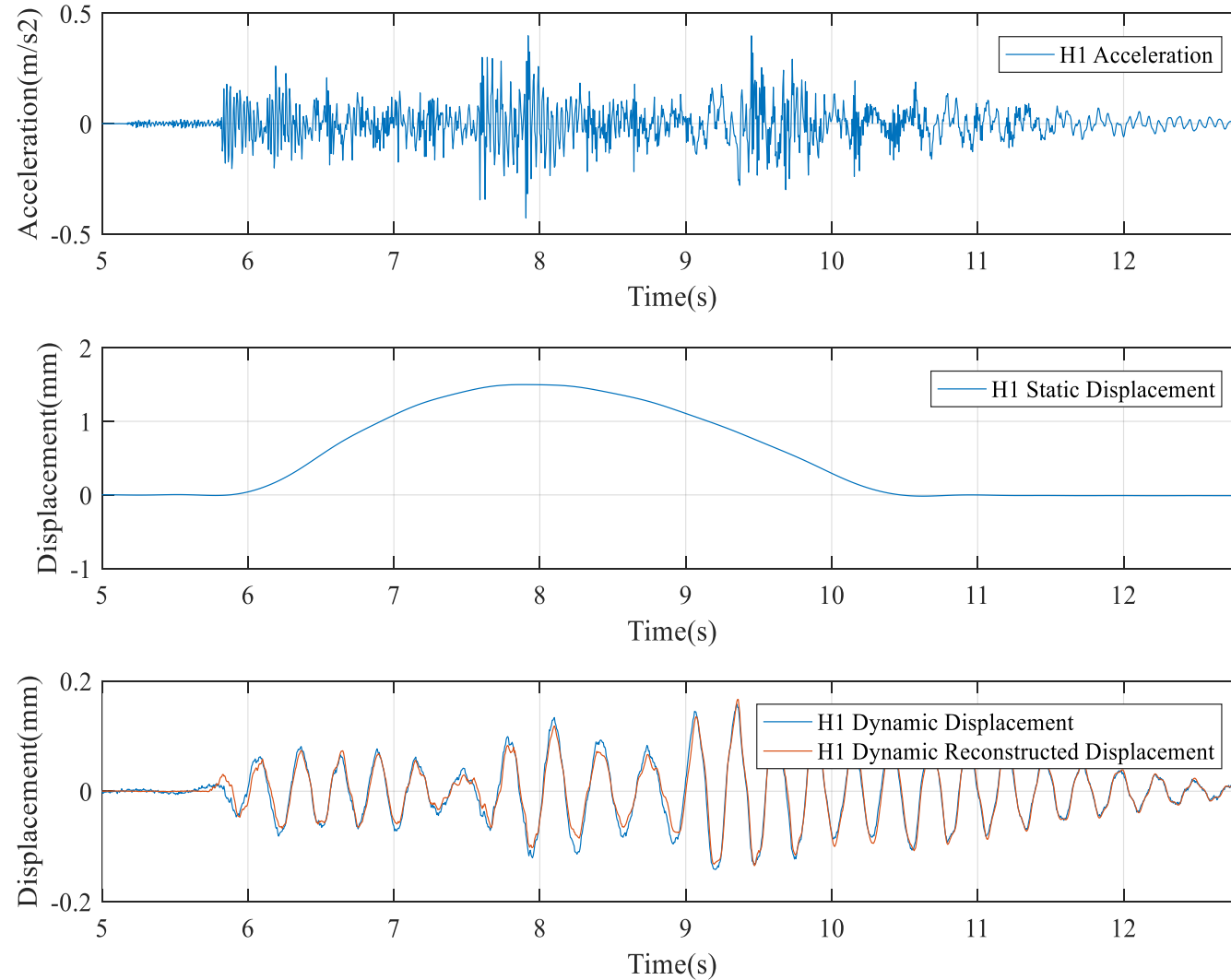
LV1B0S1

Results of experiments at Kyoto University



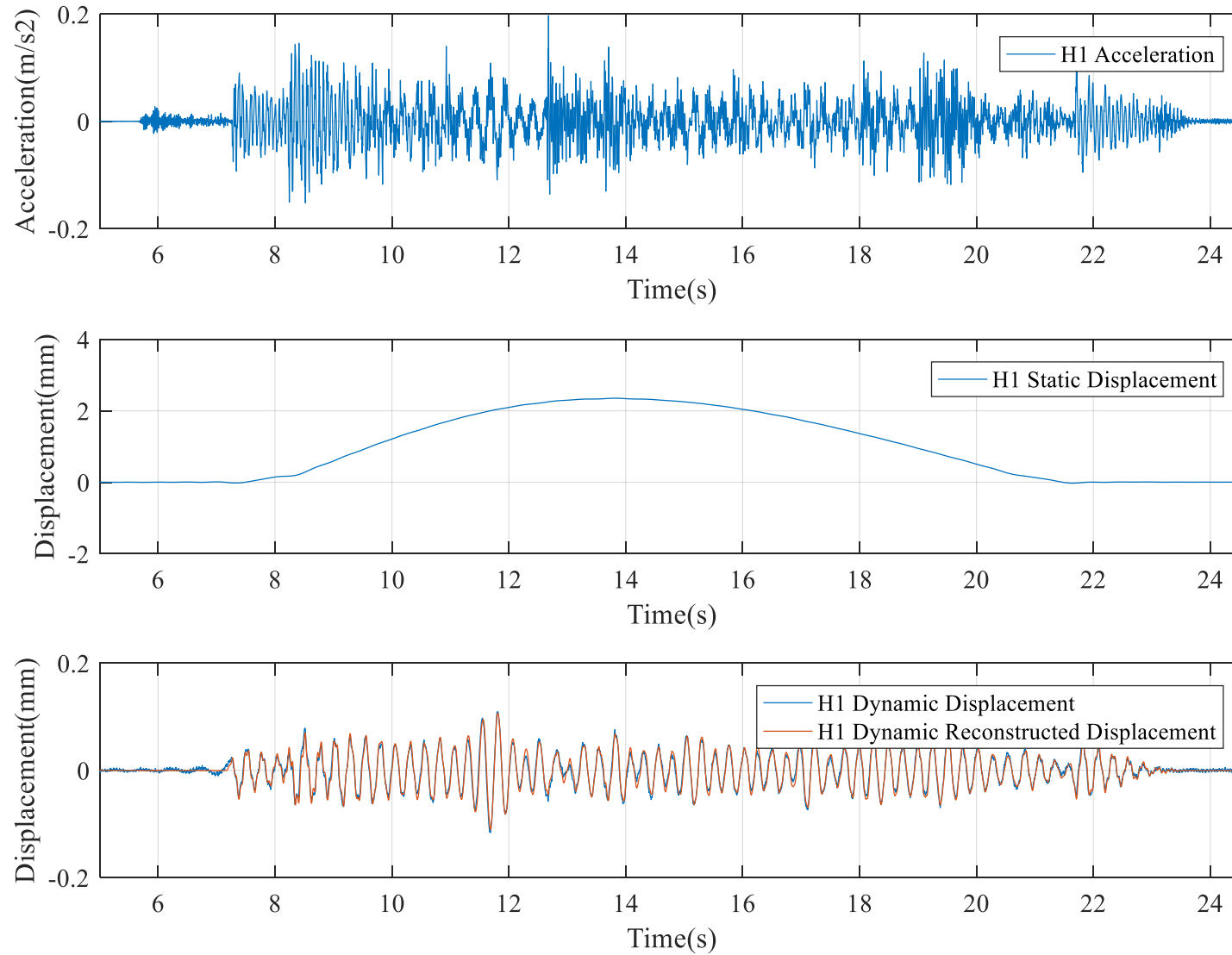
LV1B0S2

Results of experiments at Kyoto University

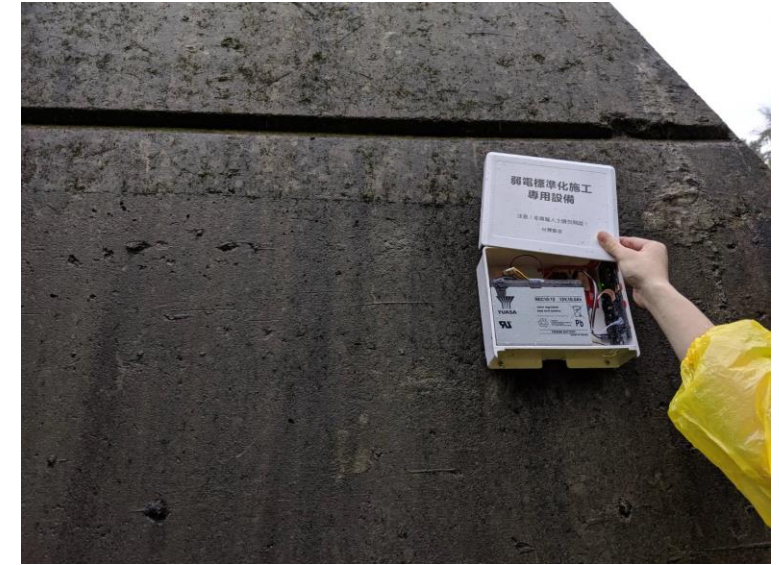


LV1B0S3

Results of experiments at Kyoto University



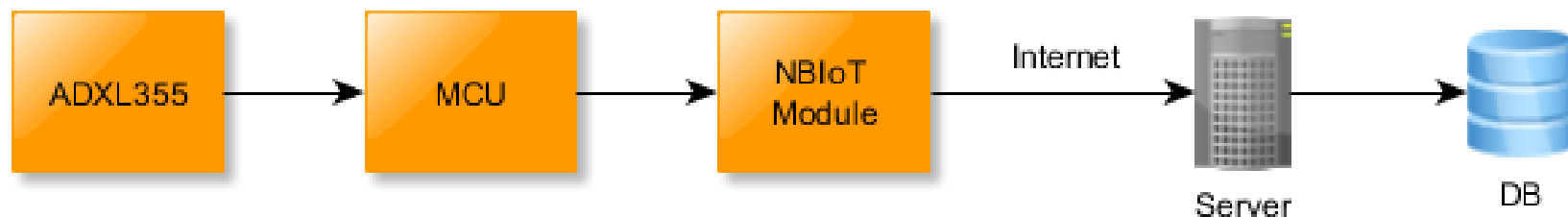
HV1B0S1



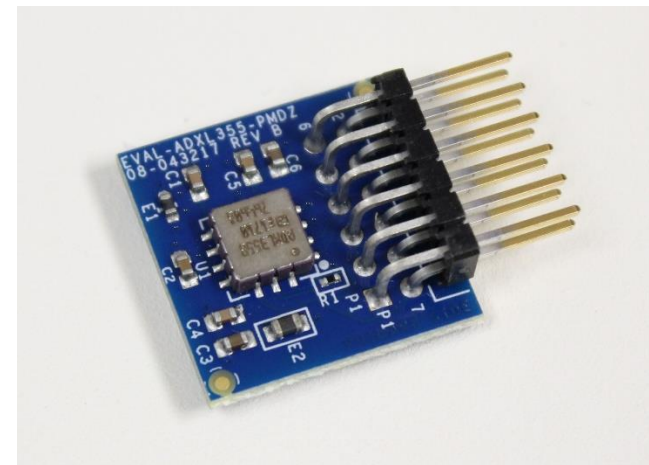
烏來忠治5號壩所設置之智慧感測元件

智慧感測器開發專案： G-Sensor 結合 NBloT 通訊 (nRF9160)

架構



- ▶ 由 MCU 搜集 ADXL355 的 G值資料, 透過 NBloT 模組, 傳送給遠端的 Server.
- ▶ Server 再將資料儲存至 Database.



ADXL355

ADXL355 參數設定

- 通訊介面: I²C
- 通訊位址: 0x1D
- 設定 FILTER 暫存器, 位址: 0x28, 值: 0x05
表示取樣頻率為 125Hz
- 啟動量測功能, 位址: 0x2D, 值: 0x00

讀取G值資料

- 檢查是否已產生資料?
讀取位址: 0x05, 若值 ≥ 3 , 則可讀取資料。
- 讀取G值
讀取位址: 0x11, 每次讀取3個位元組, 連續讀取3次, 將依序得到 Z軸, Y軸 與 X軸的 G值資料.

NB-IoT 通訊 (nRF9160)

- SDK: nRF Connect SDK
- 使用 BSD Socket 來撰寫網路通訊程式.

資料編碼

- 原始資料量: $20\text{bit} \times 3\text{軸} \times 4096\text{筆} / 8 = 30720\text{ Bytes}$
- 差值編碼法: 當 G-Sensor 晃動不大時, G 值變化也不會太大, 因此增加 2 個 bit 來記錄差值的記錄位元數, 00: 8bits, 01: 12bits, 10: 16bits, 11: 20bits
- 實測結果: 壓縮率達 50% 以上

Server 通訊

- 通訊介面: TCP
- Server IP: 13.67.95.104, Port: 3366
- 通訊格式:

Header	Encode Map	Encode Data
--------	------------	-------------

Header: 量測的資訊
Encode Map: 每筆資料的2bit對映表
Encode Data: 差值編碼的資料

未編碼前的原始資料						
取樣值	bit 數量		差值	編碼值	差值bit 數	總 bit 數
498766	20		498766	11	20	22
498847	20		81	00	8	10
498793	20		-54	00	8	10
498786	20		-7	00	8	10
498786	20		0	00	8	10
498774	20		-12	00	8	10
498762	20		-12	00	8	10
498877	20		115	00	8	10
498812	20		-65	00	8	10
498793	20		-19	00	8	10
資料總Bit 數	200				編碼後總Bit 數	112
					壓縮率	56%

資料庫儲存

- 資料庫: MySQL
- 資料表:
 - ID: Index
 - TIME: DATETIME
 - IMEI: CHAR(16)
 - DATA: BLOB

Server 資料下載

- URL: <http://13.67.95.104:3366/getrec.php>

顯示 IMEI 的清單, 點選後顯示回報的狀態, 在最上方可輸入日期範圍下載資料.

例: 欲下載11月1日~11月10日,
Start:2019-11-01, End: 2019-11-11

Download Records:

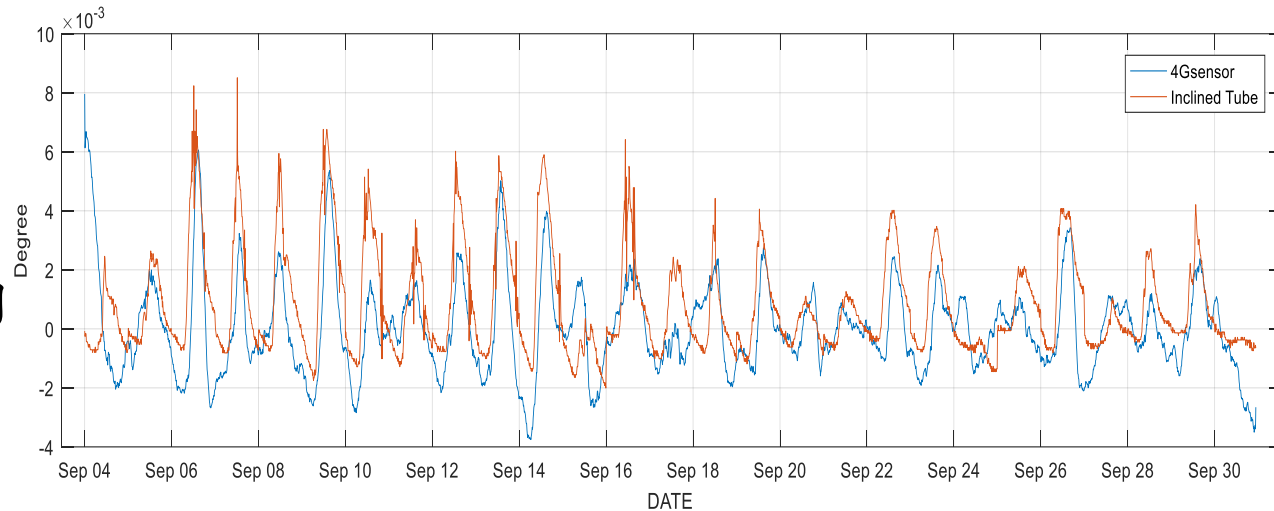
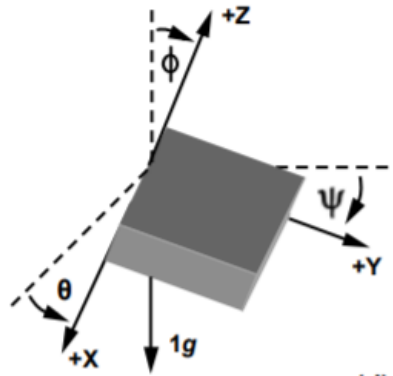
Start: 2019-11-01

End: 2019-11-11

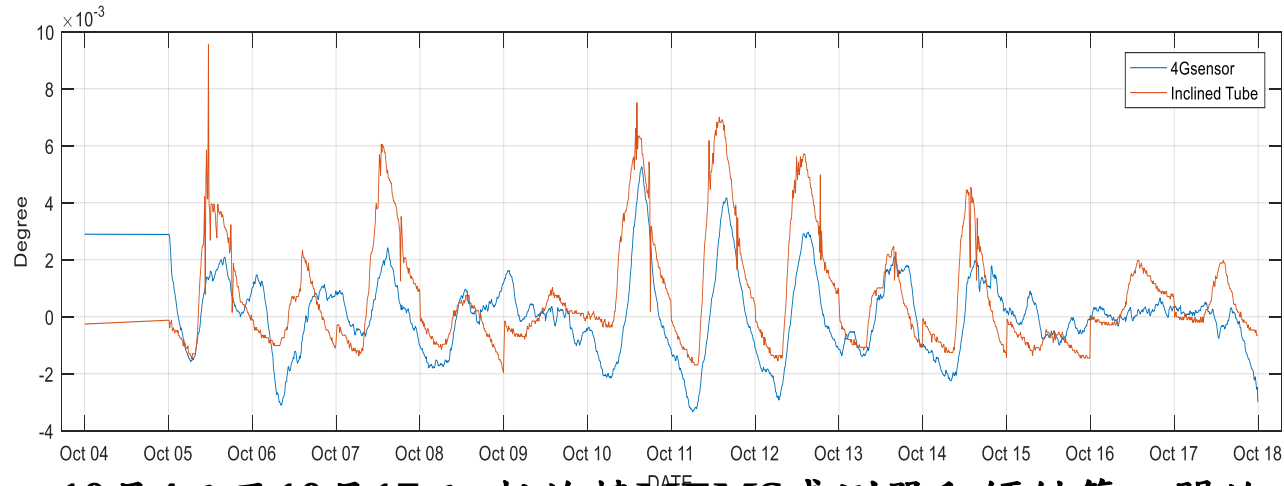
送出查詢

現地量測資料數據分析

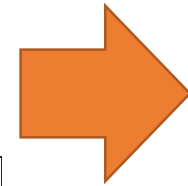
MEMS感測器傾角之驗證



9月4日至10月1日y軸旋轉MEMS感測器和傾斜管之間的傾斜角測量結果比較圖

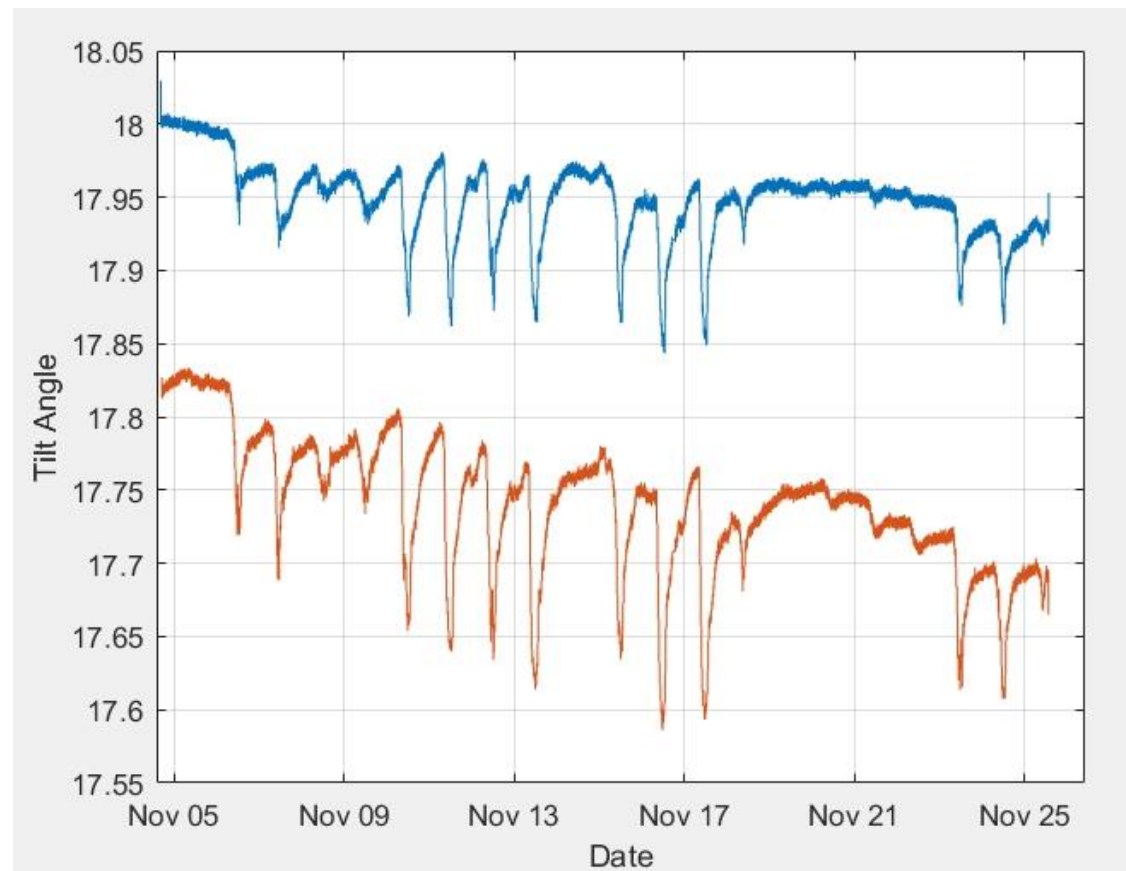
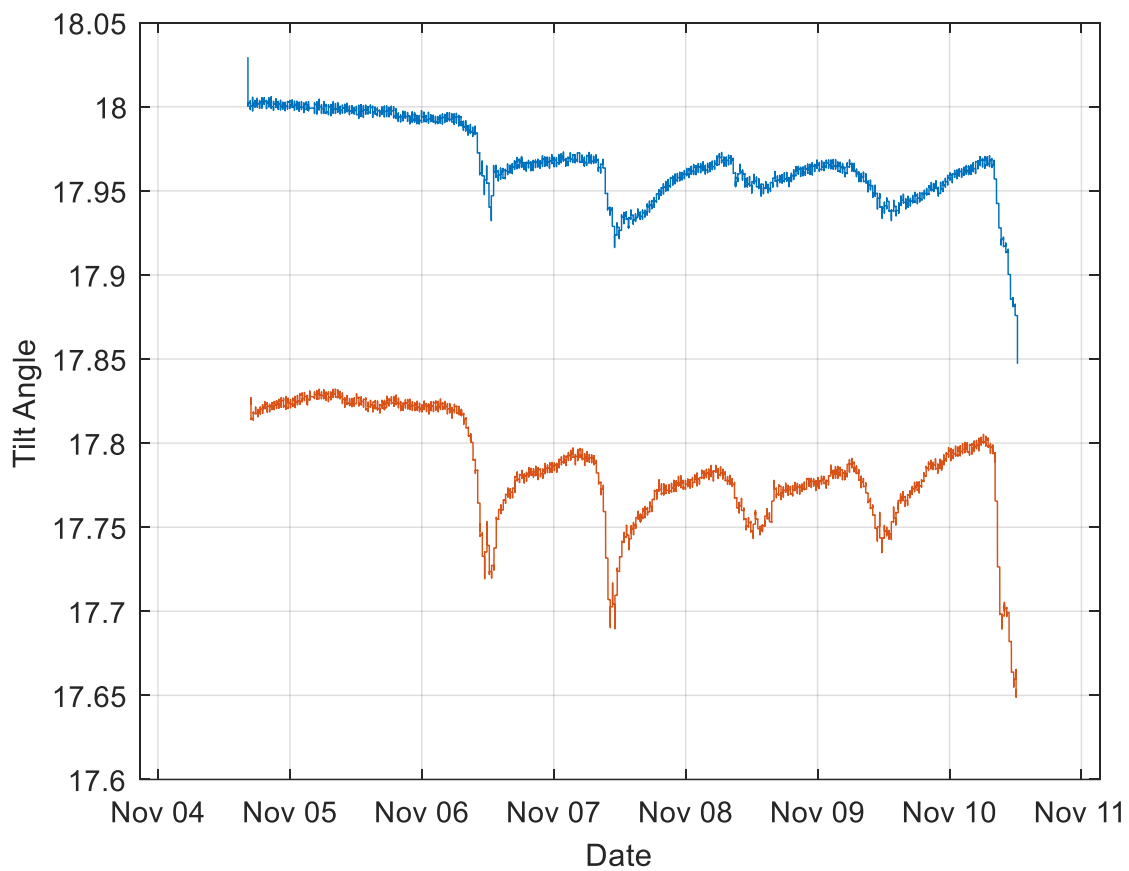


10月4日至10月17日y軸旋轉MEMS感測器和傾斜管之間的傾斜角測量結果比較圖



關係良好

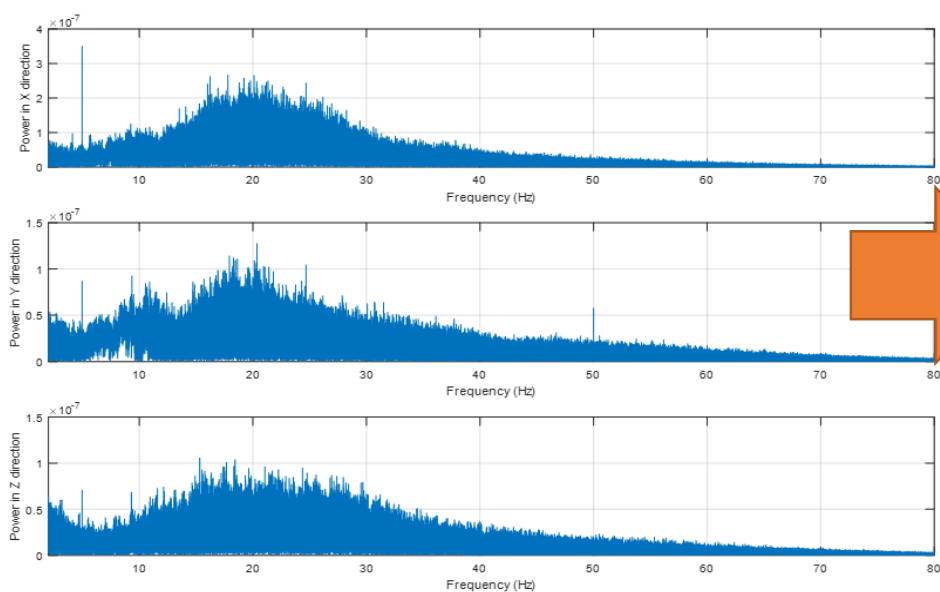
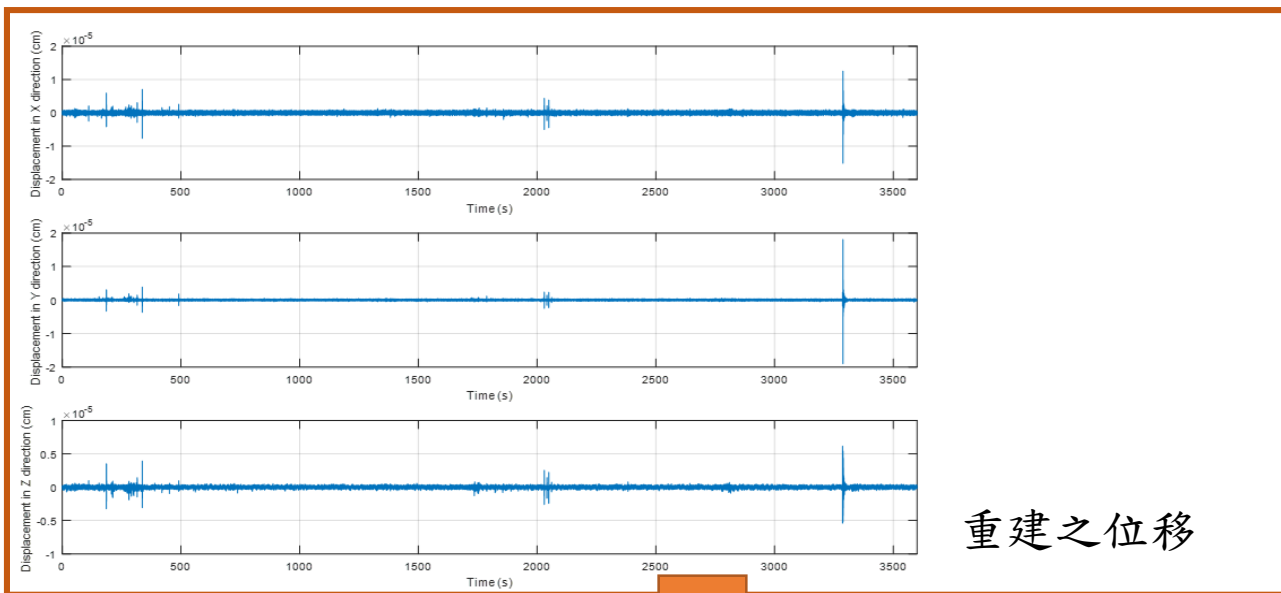
烏來忠治現地量測資料



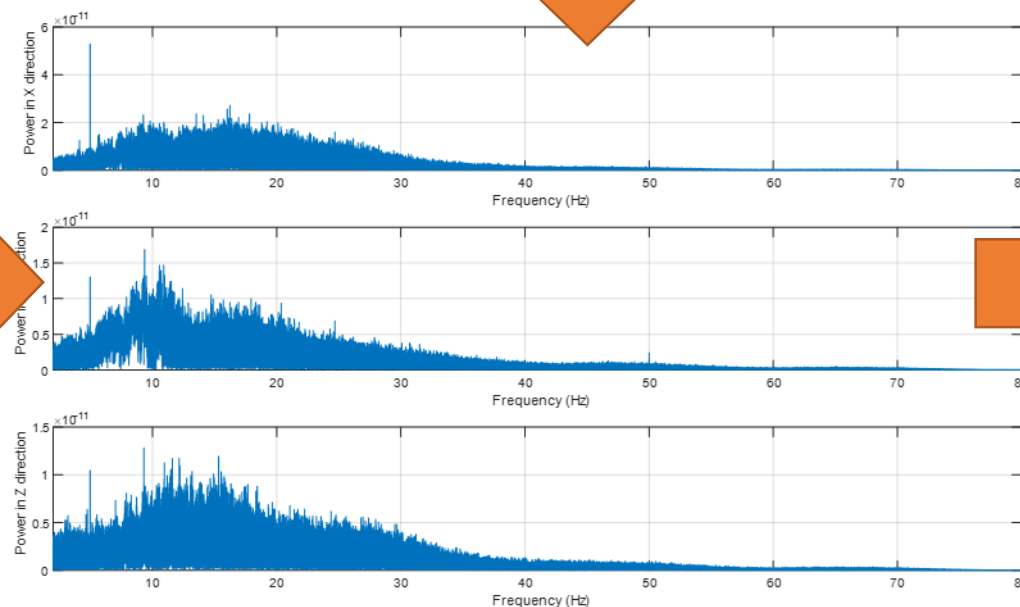
位移之計算

$$\text{Min}_u \Pi_E(u) = \frac{1}{2} \int_{T_1}^{T_2} (a(u(t)) - \bar{a})^2 dt$$

$$\text{Min}_u \Pi_E(u) = 0.5 \|L_a(a - \bar{a})\|_2^2 \Delta t + 0.5 \lambda^2 \|u\|_2^2$$



原始資料之FFT

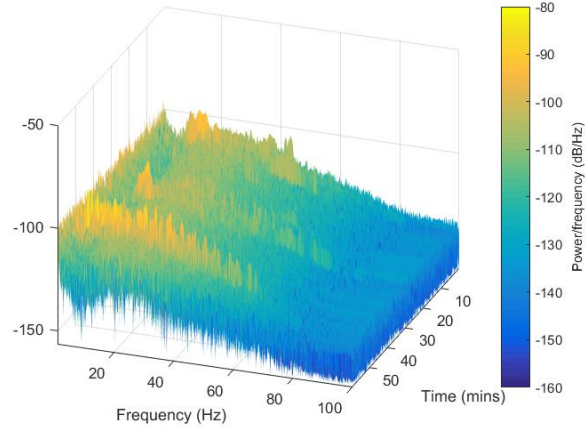


重建位移之FFT

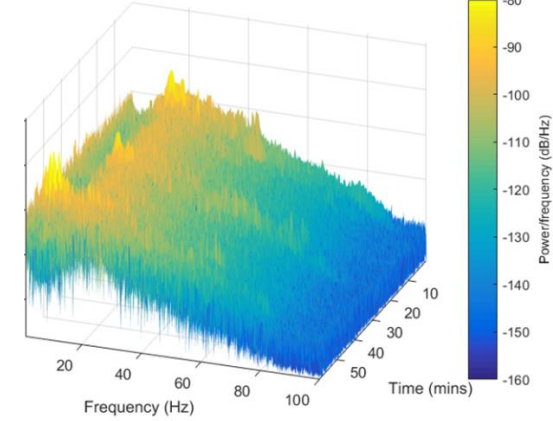
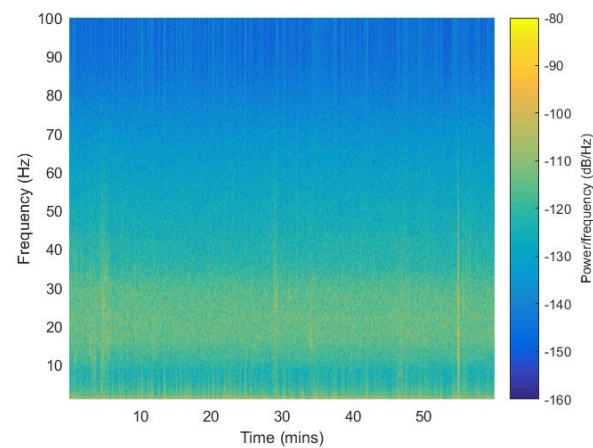
低頻雜訊消除

現地量測資料數據分析 — 以高精密度速度計資料為輸入

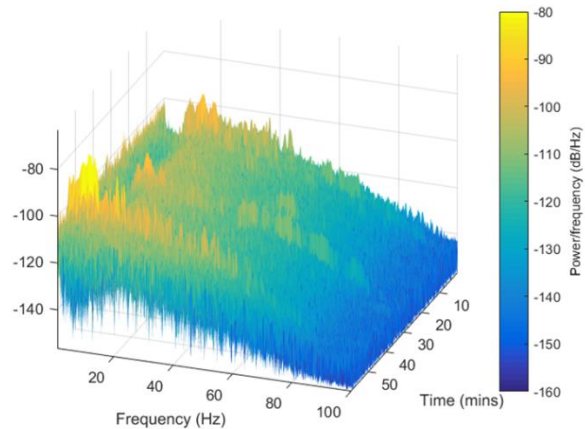
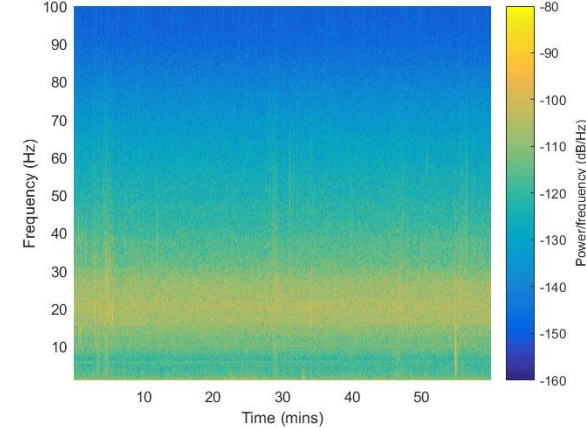
設施基本振動頻率之計算



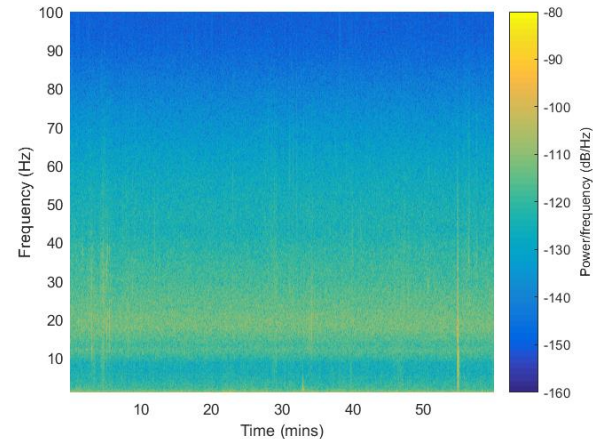
FFT Spectrogram in X direction



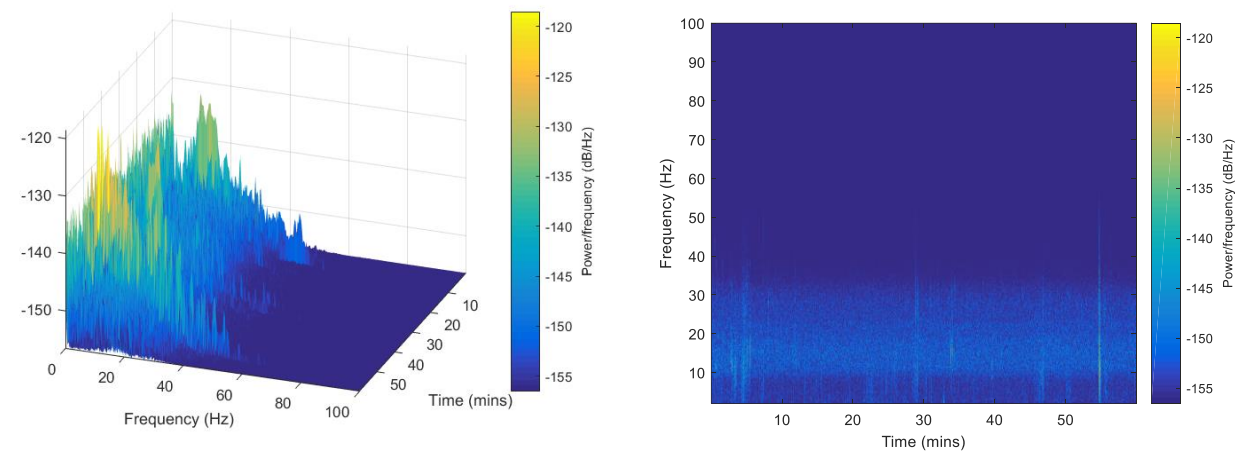
FFT Spectrogram in Z direction



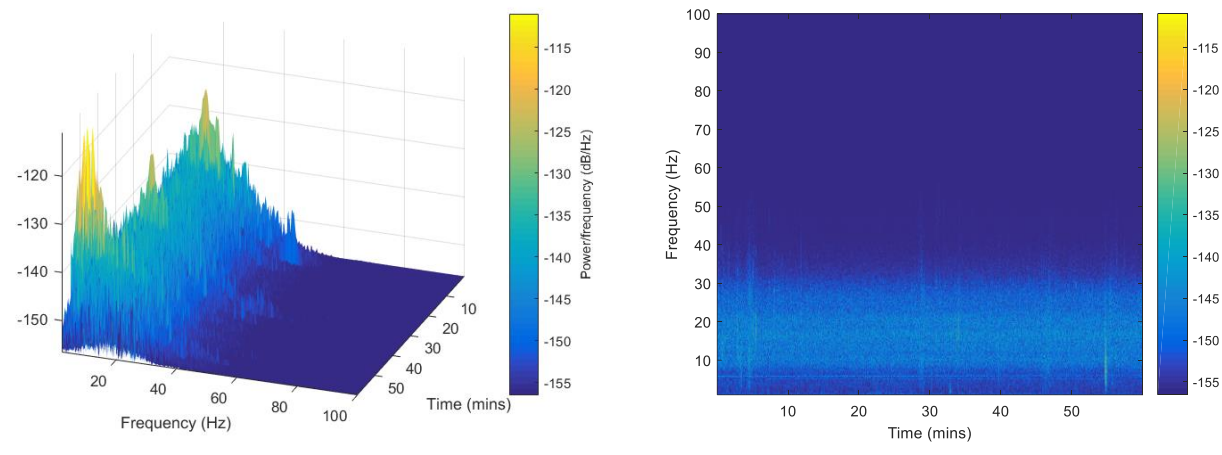
FFT Spectrogram in Y direction



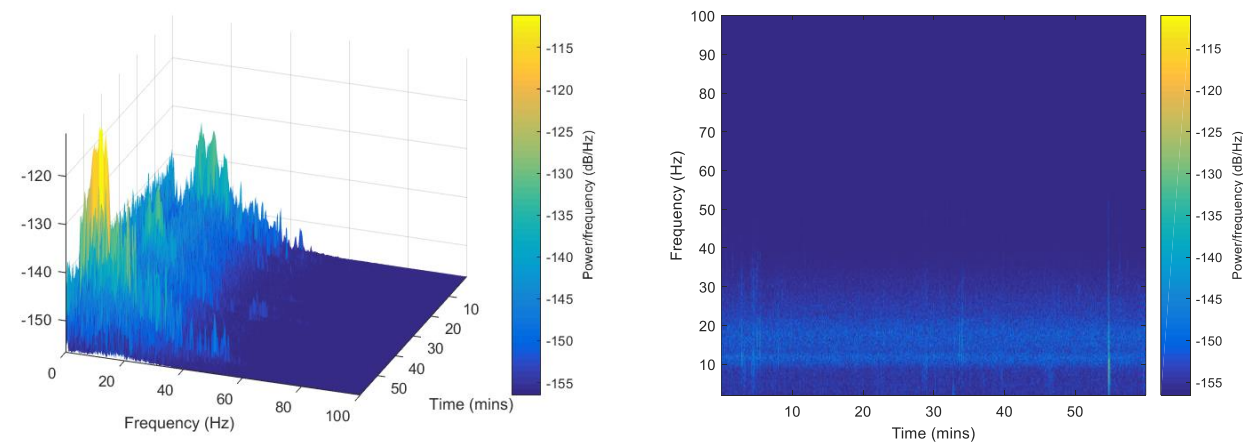
設施基本振動頻率之計算 (以重建位移為輸入)



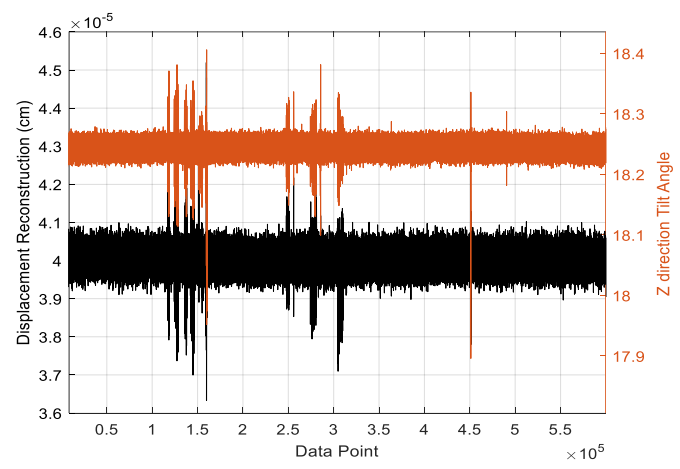
FFT Spectrogram in X direction



FFT Spectrogram in Z direction



FFT Spectrogram in Y direction



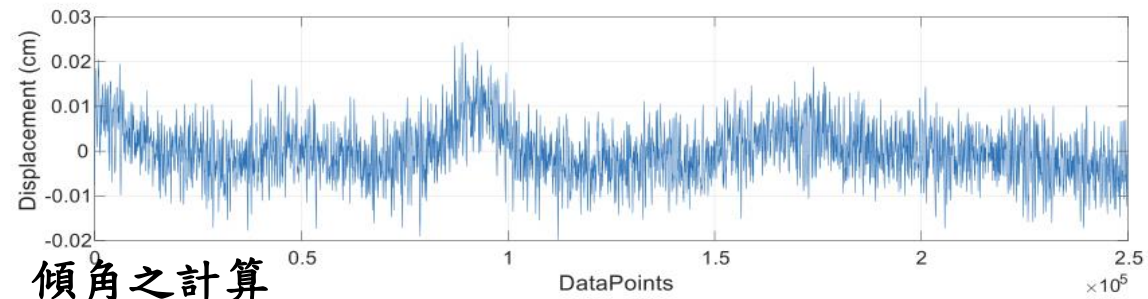
重建位移與傾斜角之關係圖

Spectrogram與
原始資料相近

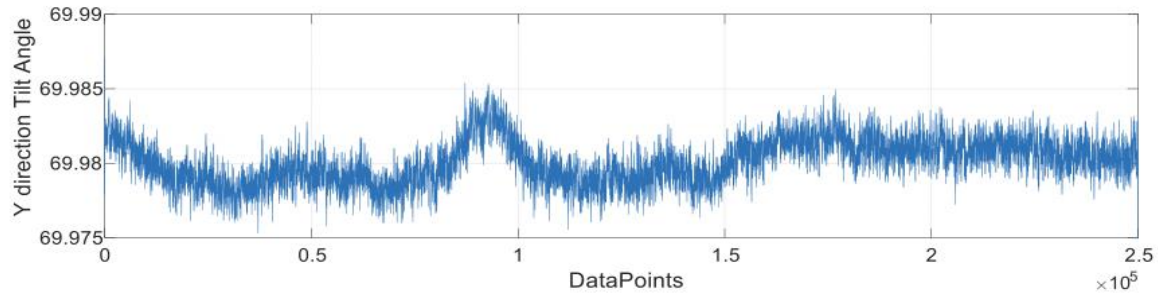
位移與傾角具
有高度相關

現地量測資料數據分析

位移之計算

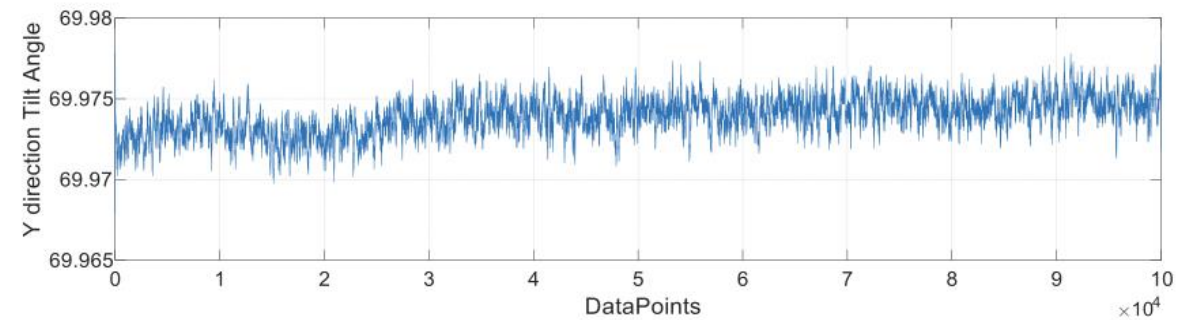
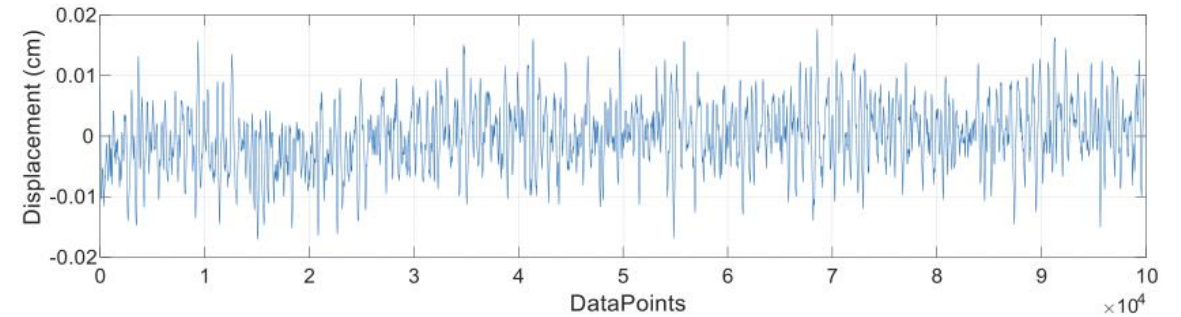


傾角之計算



米塔颱風測得數據重建之位移與y軸傾斜角之關係圖

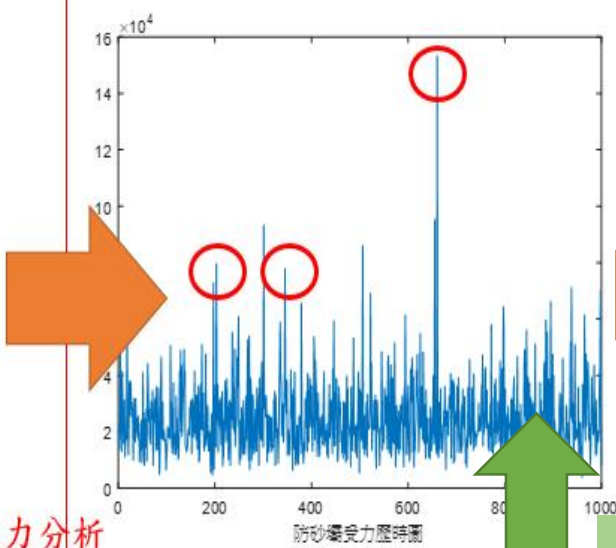
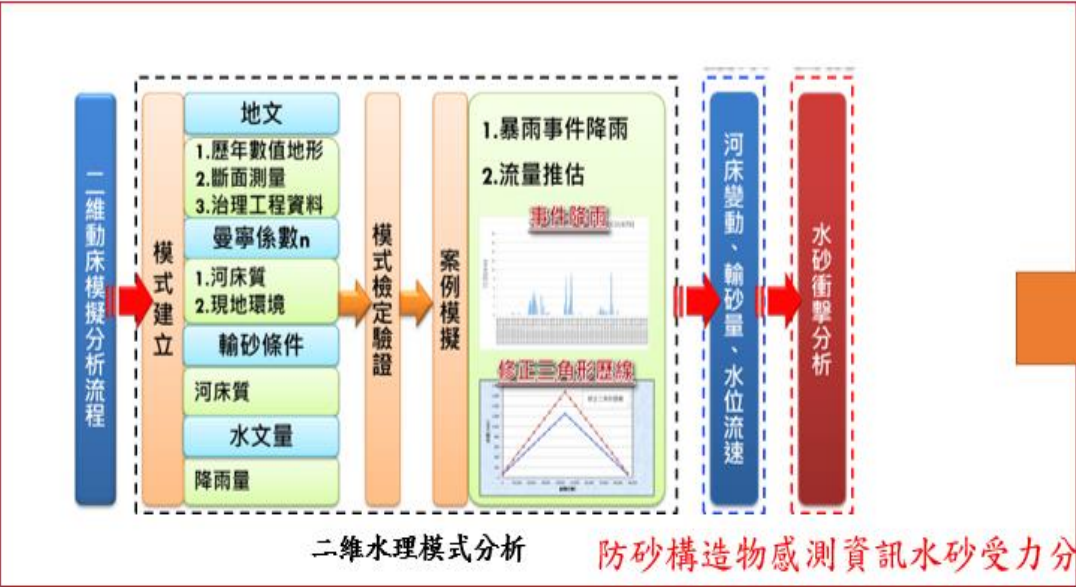
關係良好



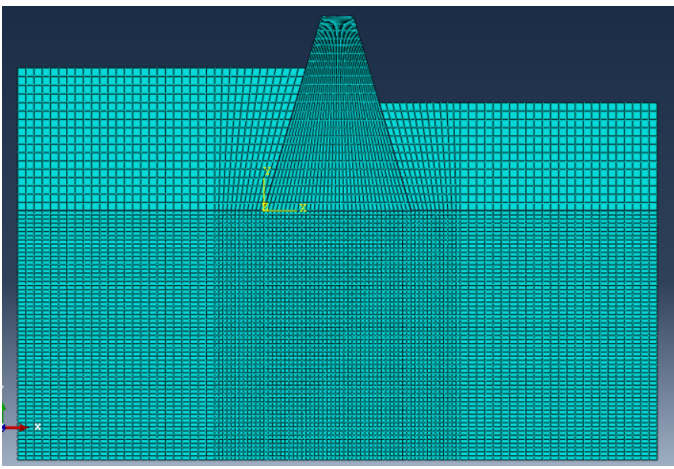
米塔颱風測得數據重建之位移與z軸傾斜角之關係圖

防砂壩安全分析

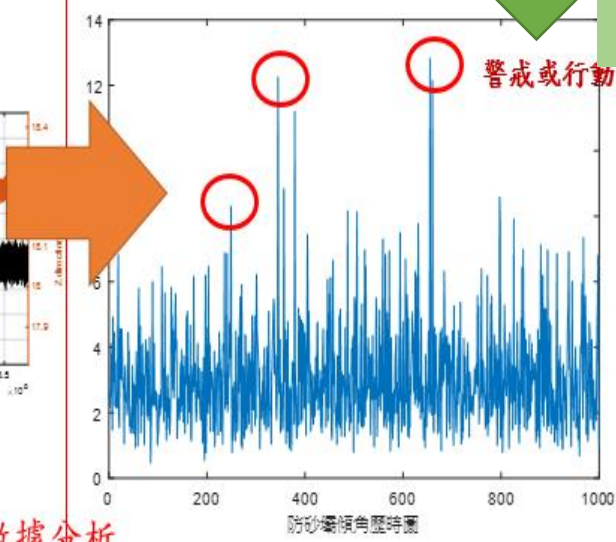
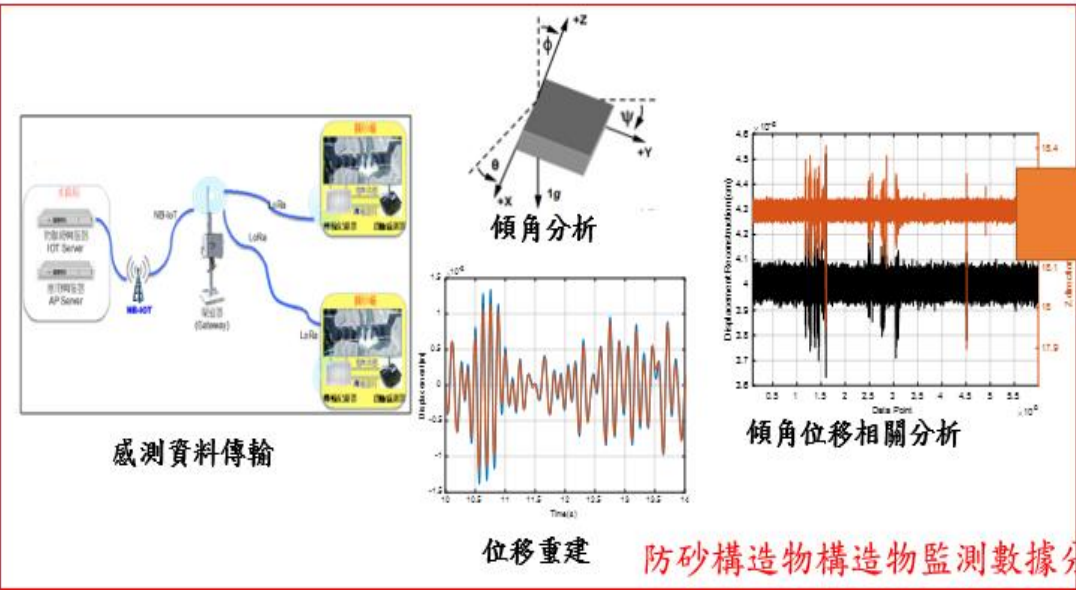
以ABAQUS有限元素分析



目前資料
無明顯相關性

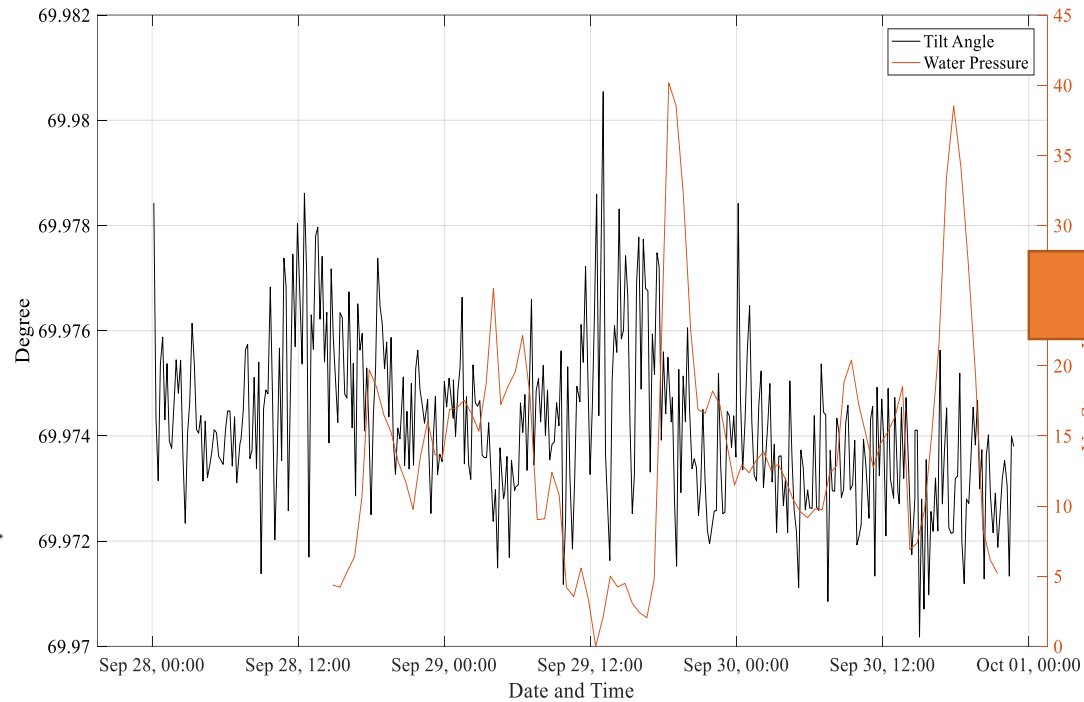
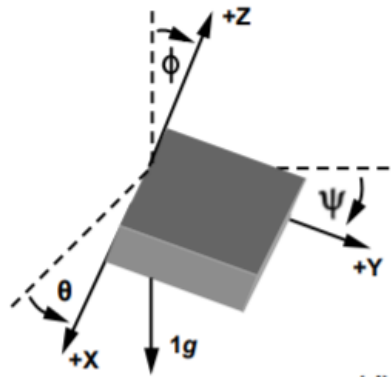


管理值訂定



現地量測資料數據分析

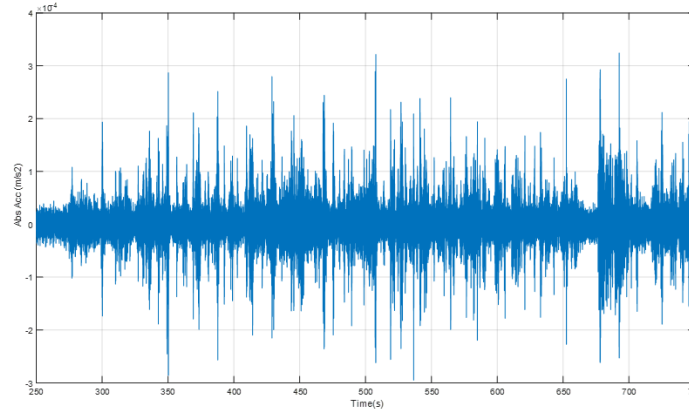
MEMS傾角 與水壓之關係圖



米塔颱風前後壩體上游水壓(紅色)與
傾斜角度(黑色)之關係圖

資料不足或水壓強度
不強，關係不明顯

基於位移重建之防砂壩系統識別分析(容量分析)

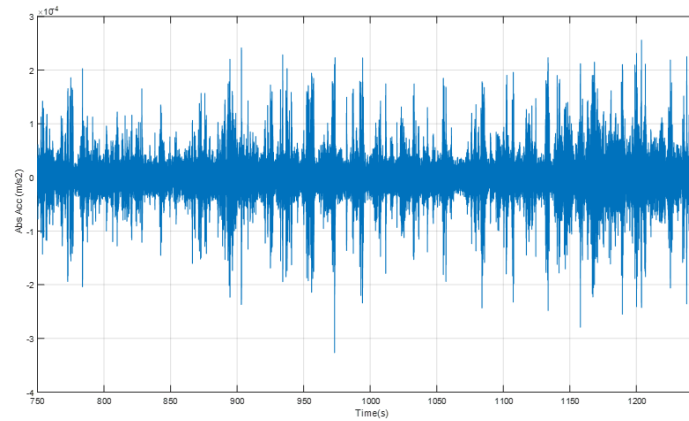


第一振態頻率 (Hz)

12.27

阻尼比 (%)

10.50

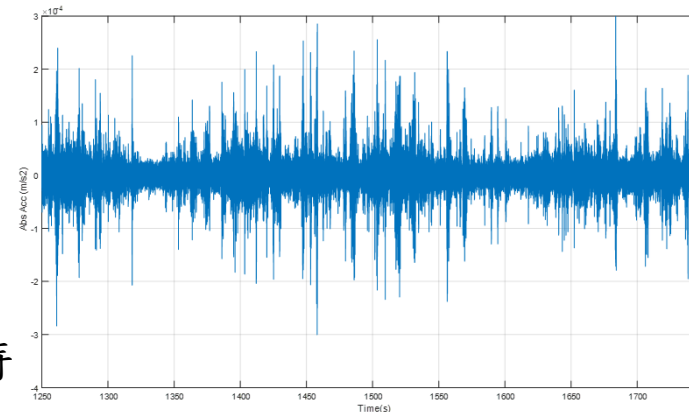


第一振態頻率 (Hz)

12.24

阻尼比 (%)

9.89



第一振態頻率 (Hz)

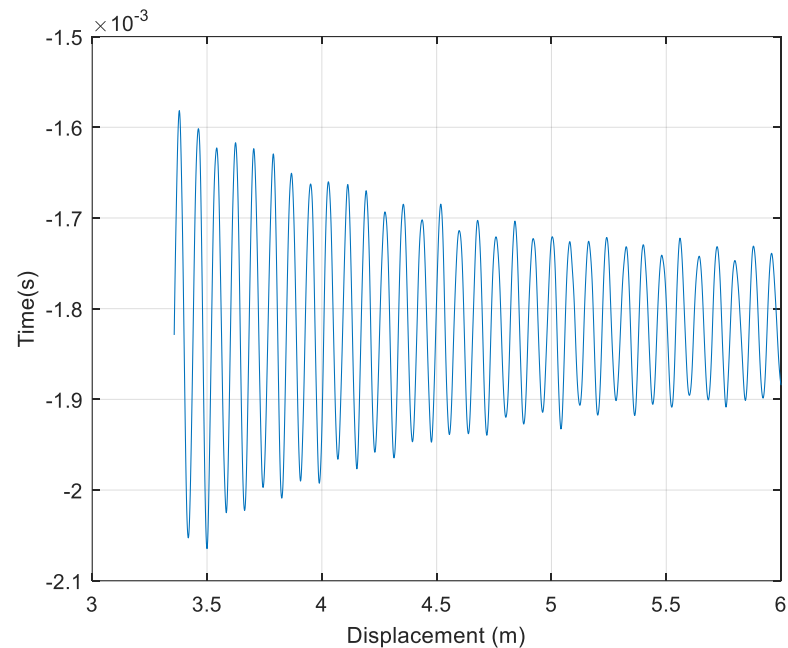
12.14

阻尼比 (%)

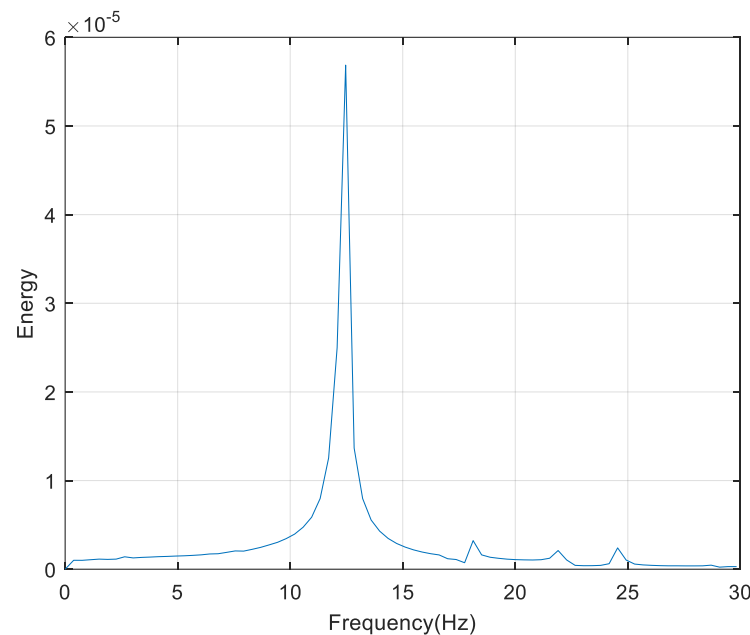
12.59

加速度歷時

基於重建位移之有限元素模型 (容量分析)



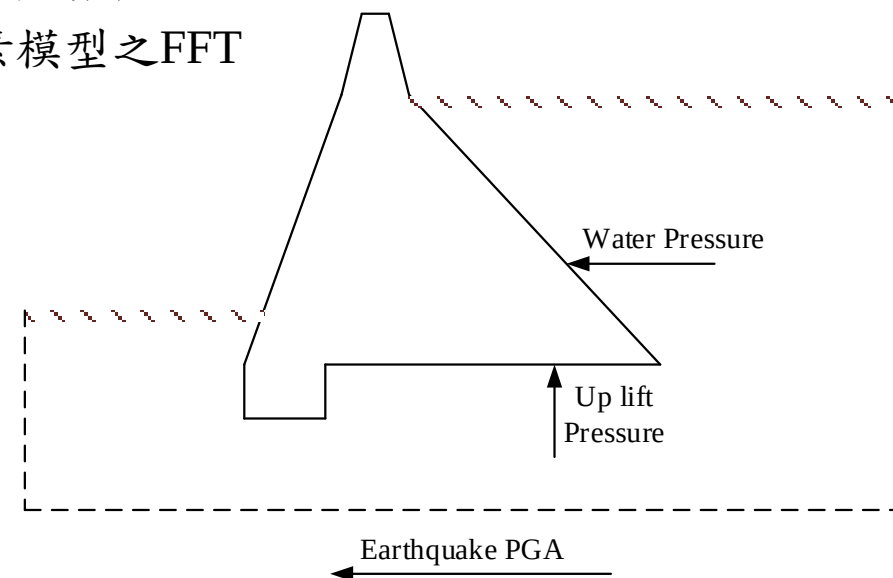
有限元素模型之自由振動歷時反應



有限元素模型之FFT

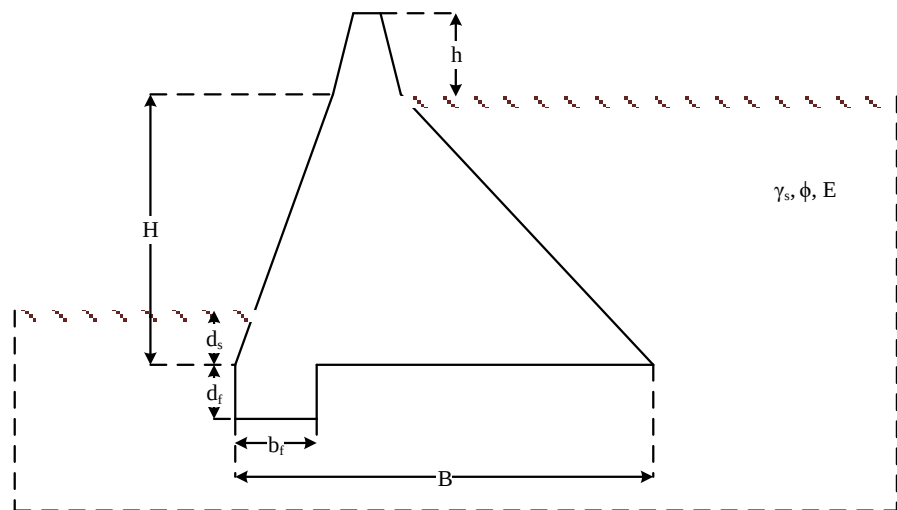
本計畫所考慮之參數

Variable	Min	Max	Increment
Water Depth (m)	2.50	12.00	0.50
Uplift Pressure (tf)	35.00	44.00	3.00
PGA (g)	0.00	0.30	0.10

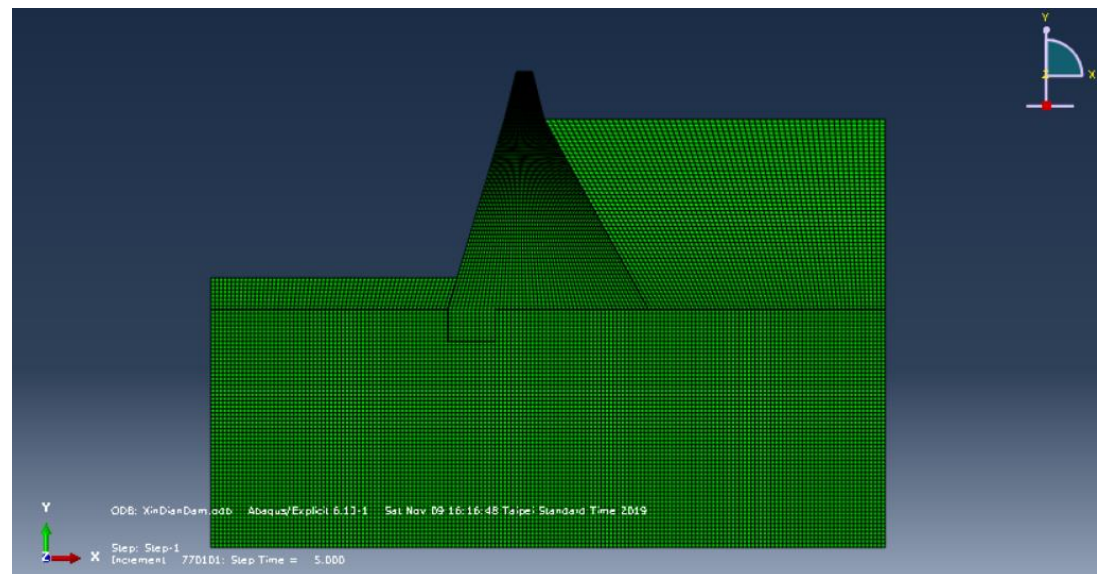


有限元素模型與考慮的外力

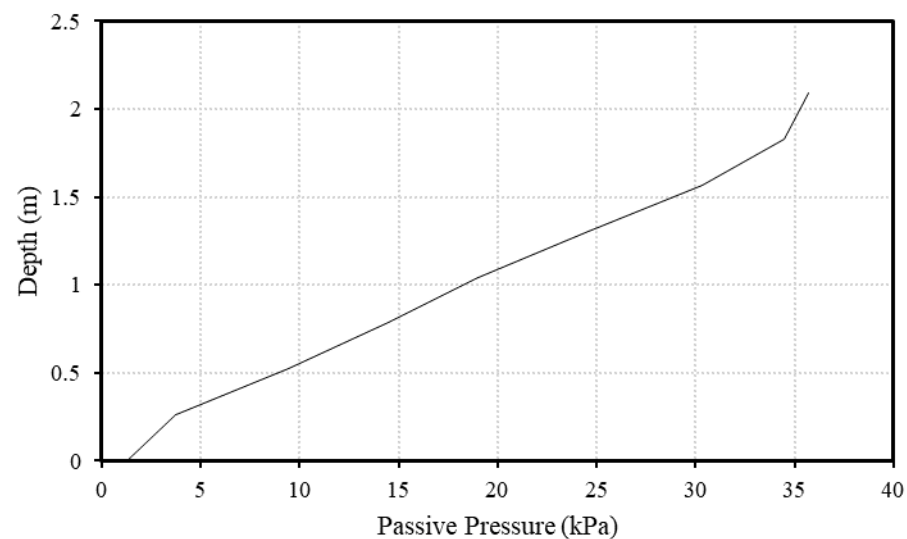
基於重建位移之有限元素模型 (容量分析)



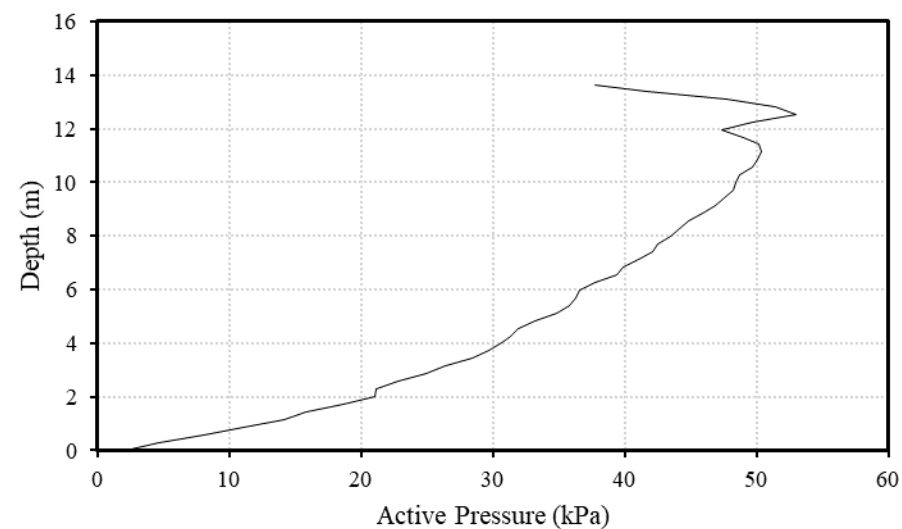
5號壩的尺寸示意圖



有限元素模型

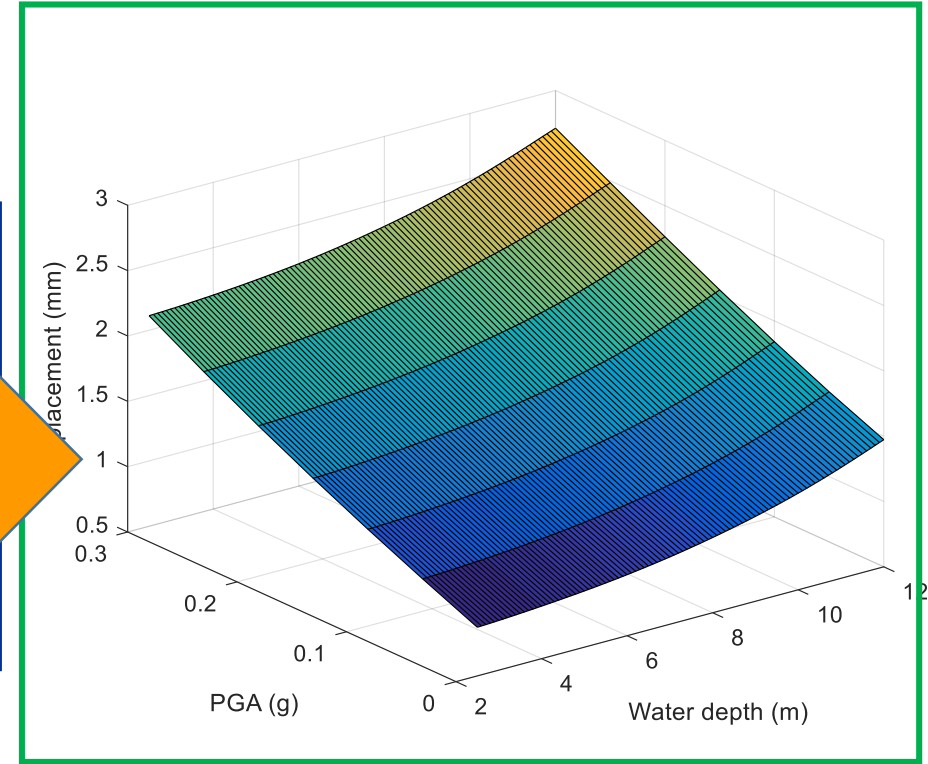
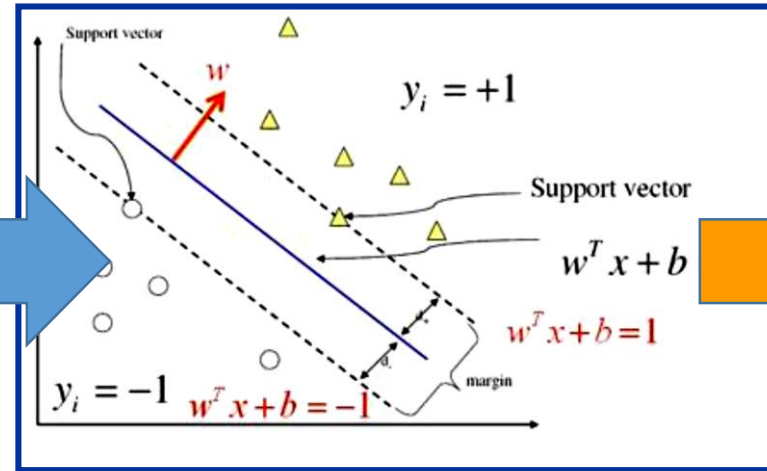
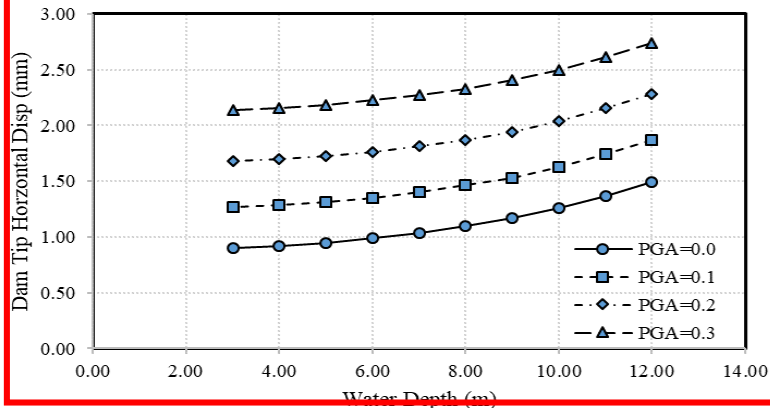
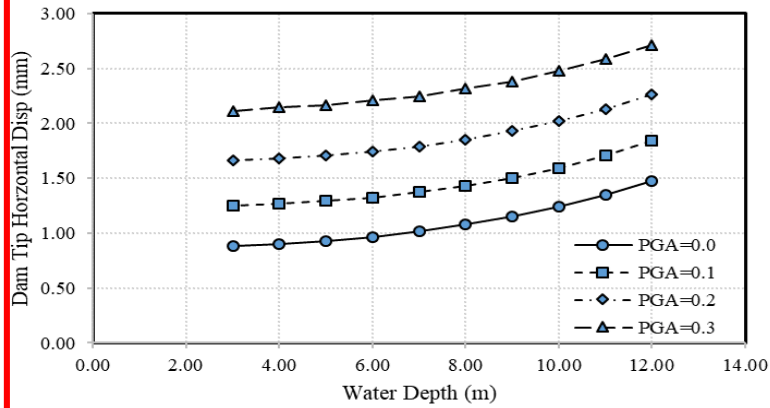
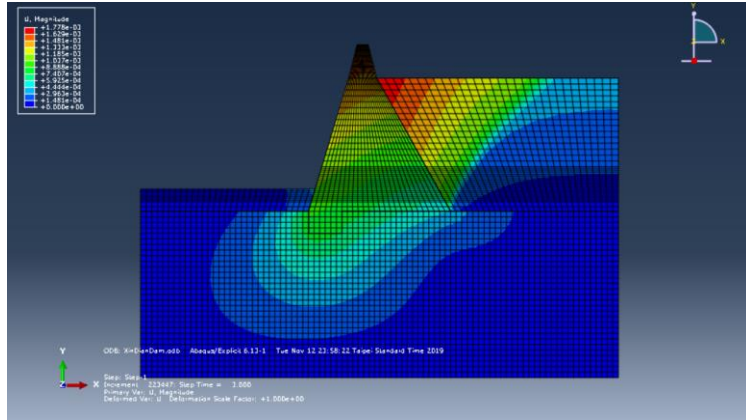


被動土壓力分布圖



主動土壓力分布圖

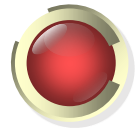
基於位移重建之防砂壩機器學習分析(需求分析)

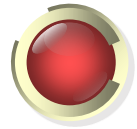


結論

- 成功結合感測器、IoT技術，與研發位移重建技術
- 位移重建技術經數值、室內(NCREE與京都大學)驗證
- 運用所開發技術於烏來忠治防砂壩之監測
- 利用重建位移建立有限元素模型(容量)
- 利用有限元素模型與支持向量機建立預測模型(需求)

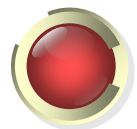
討論

 電力、訊號、成本

 水土保持設施的獨特性、管理行動值與普及性

 單一設施長期的數據觀察

 單一設施的數值模擬分析

 研究的延續性? **Every effort counts**

關鍵指標的建立?

統計資料時空的不確定性

簡報完畢，謝謝聆聽！
Thanks for your attention