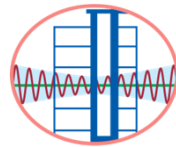
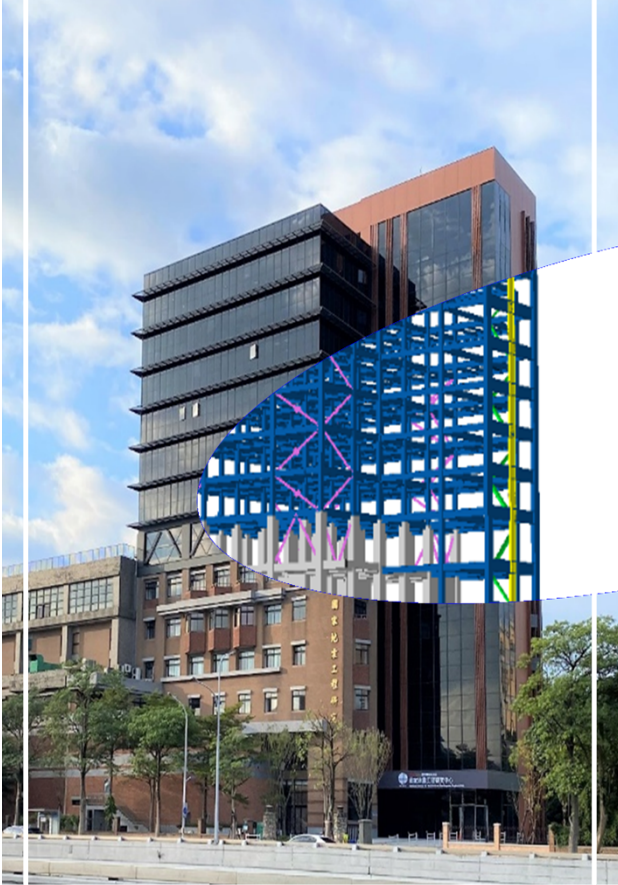


# 2024/04/03花蓮地震 國震中心辦公大樓受震反應 初步分析

## Post-earthquake Response Estimation of the NCREE Office Building Subjected to 2024/04/03 Hualien Earthquake



National Center for Research on  
Earthquake Engineering (NCREE)

**Dr. Ming-Chieh Chuang**  
**Dr. Jui-Liang Lin**



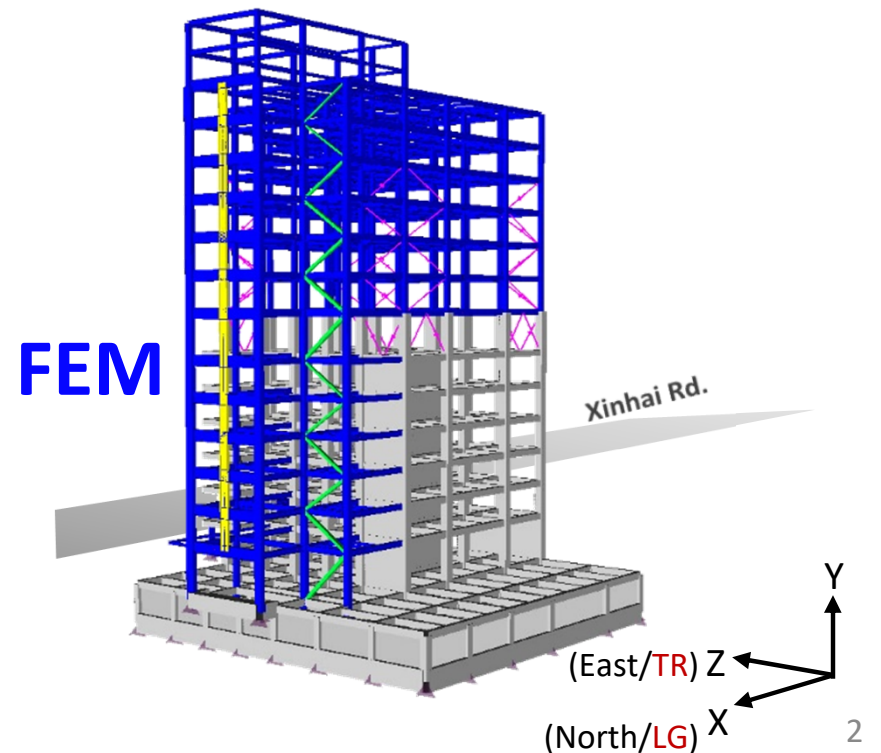
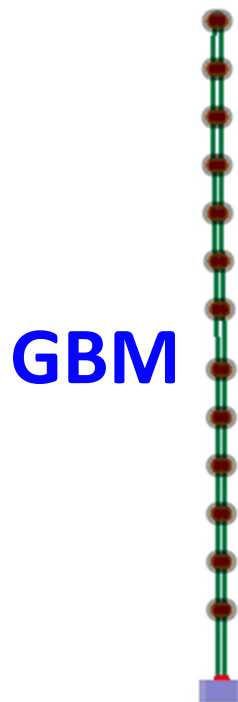
National Taiwan University

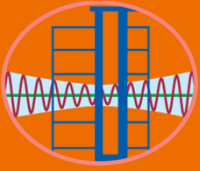
**Prof. Keh-Chyuan Tsai**  
**Prof. Shyh-Jiann Hwang**

April 8, 2024

# Outline

1. The **Instrumented** Building of NCREE
2. **2024/04/03** Hualien Earthquake ( $M_L = 7.2$ )
3. Post-earthquake Response Estimation
  - Generalized Building Model (**GBM**)
  - Finite Element Model (**FEM**)
4. Conclusions





# The Instrumented Building of NCREE

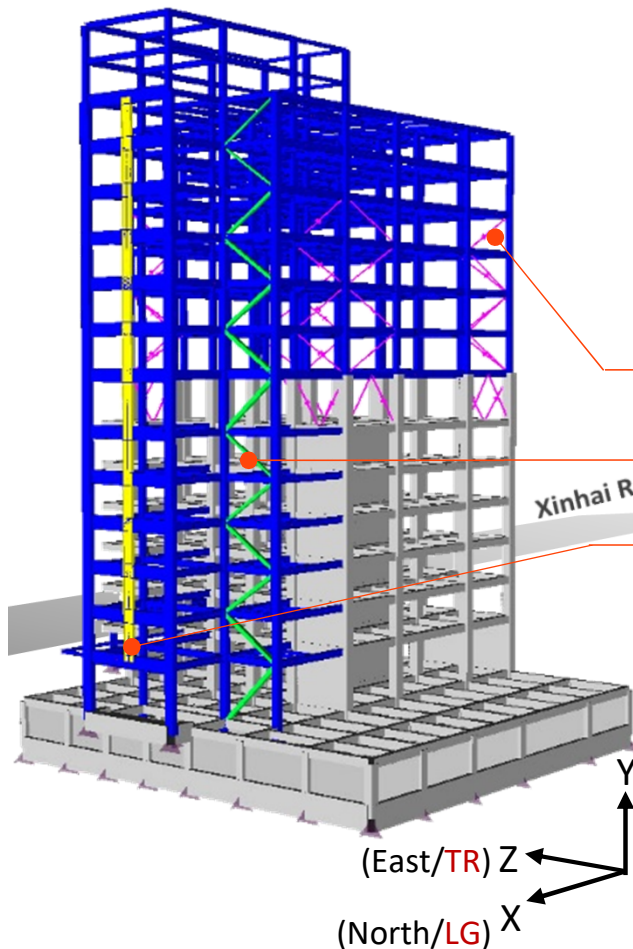
# Features of the Extended Office Building

## □ 13-story Compound Building

- RC structure (pre-existing B1-6F)
- Steel structure (added 7F-13F and service core)
- SRC structure (columns of 7F and service core)

## □ Seismic Dampers

-  Fluid Viscous Damper (FVD) (7F~11F; 48 units)
-  Buckling-Restrained Brace (BRB) (1F~13F; 13 units)
-  Steel Panel Damper (SPD) (2F~13F; 12 units)



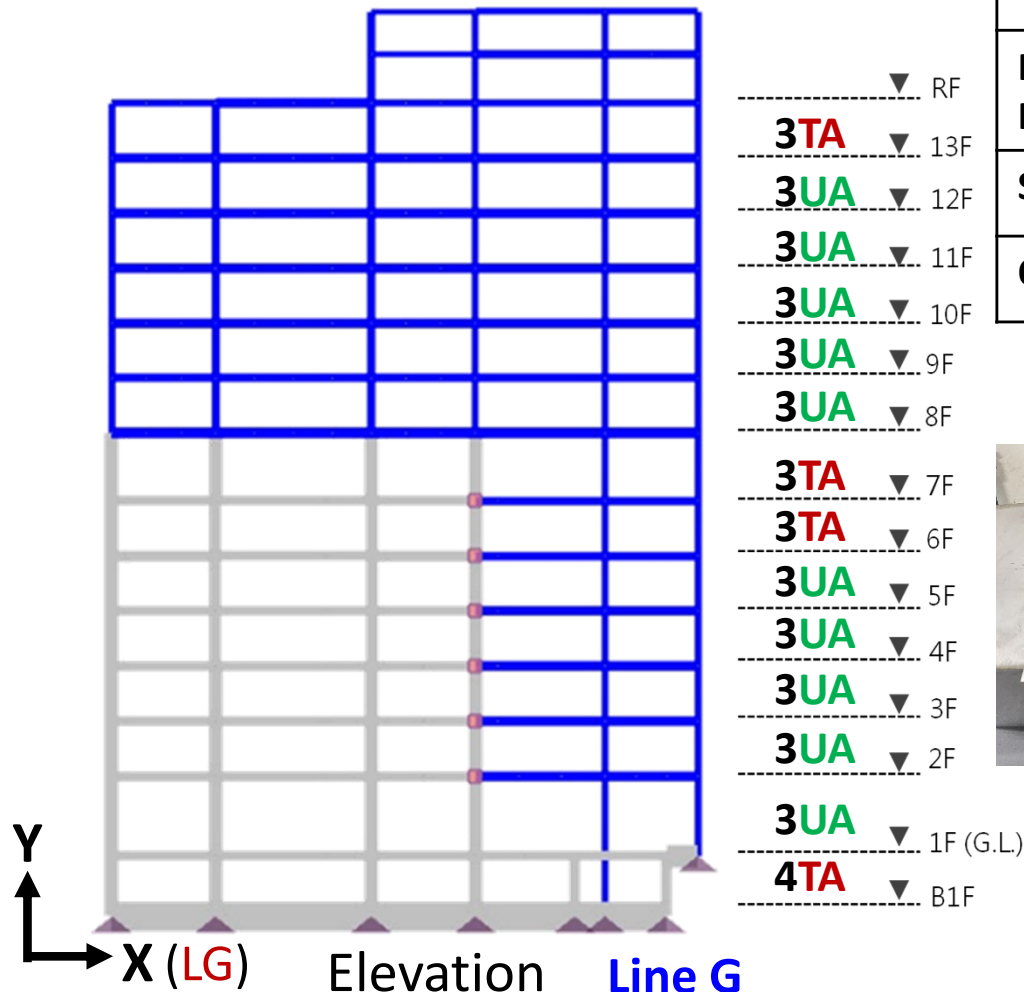
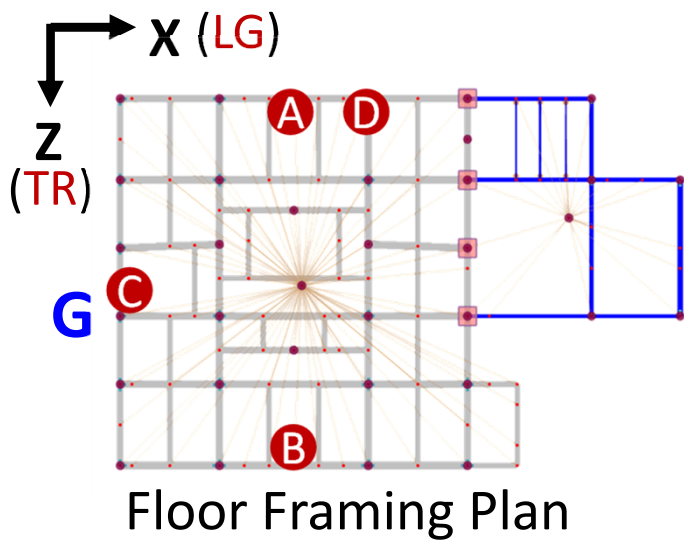
## □ Structural System

- X direction : MRF+Shear Wall+FVD  
(LG=Longitudinal)
- Z direction : MRF+Shear Wall+FVD+SPD+BRB  
(TR=Transverse)

Building Weight: **12,000 tf**  
(above ground)



# Instrumentation Layout



	Triaxial Accelerometers (TA)	Uniaxial Accelerometers (UA)
Model	Tokyo Sokushin AS-303D1W2	Tokyo Sokushin AS-305C1W5
Full Scale Range	±2000 gal	
Scale Factor	5 mV/gal	
Quantity	<b>13</b>	<b>30</b>

Sampling rate of DAQ: 200 Hz



TA on floor



TA on ceiling

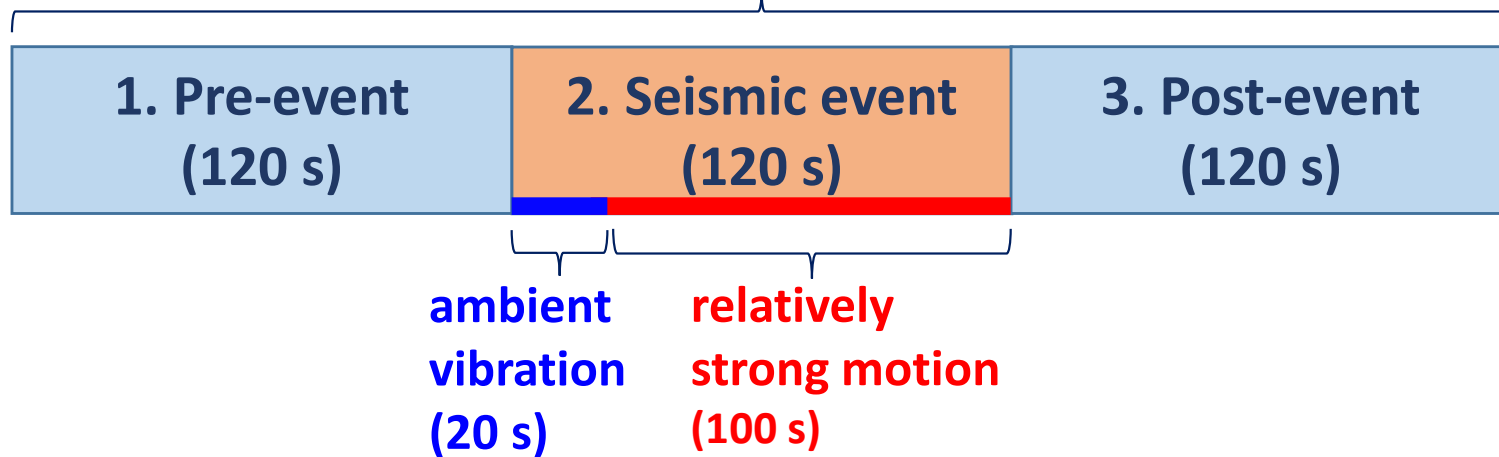


UA on ceiling

# Acceleration (Acc.) Records Obtained from NCREE's Smart Structural Monitoring System (SSMS)

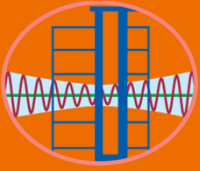
## SSMS's record format

(length of time : 360 s ; number of data points: 72,000 )



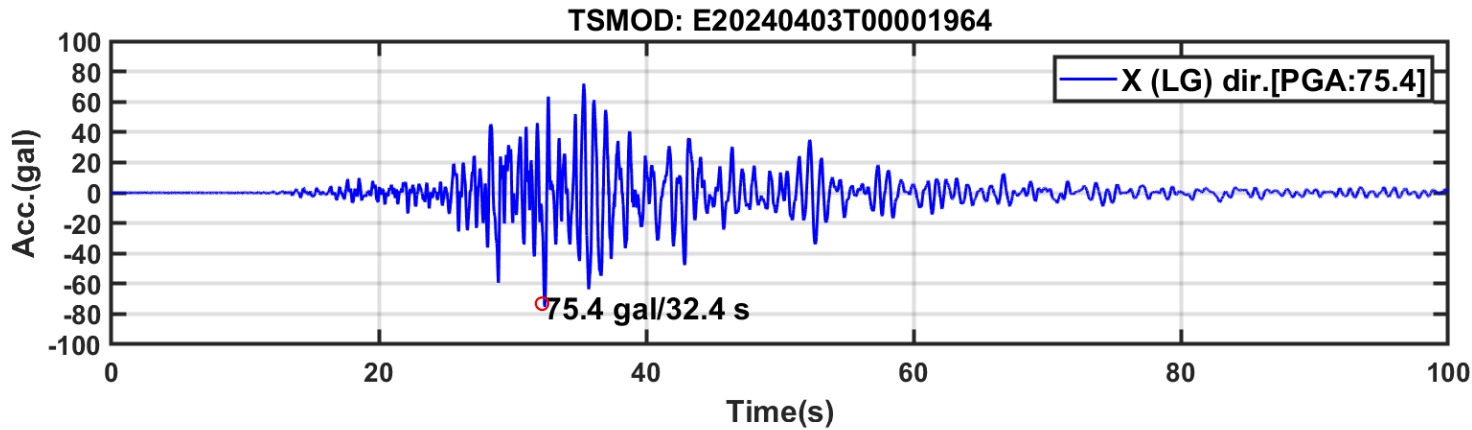
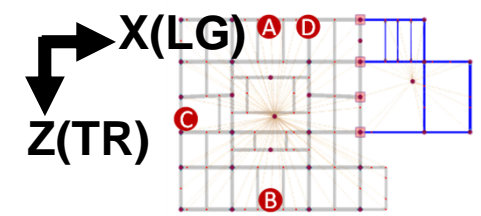
## Data Preprocessing

- The **10-second** records prior to the “**relatively strong motion data**” are incorporated into the records for RHA.
- The **random noises** following the **uniform distribution** are assumed.
- The **averaged records** in the first trimmed part (140 s) are used to **correct** the **adopted records**.

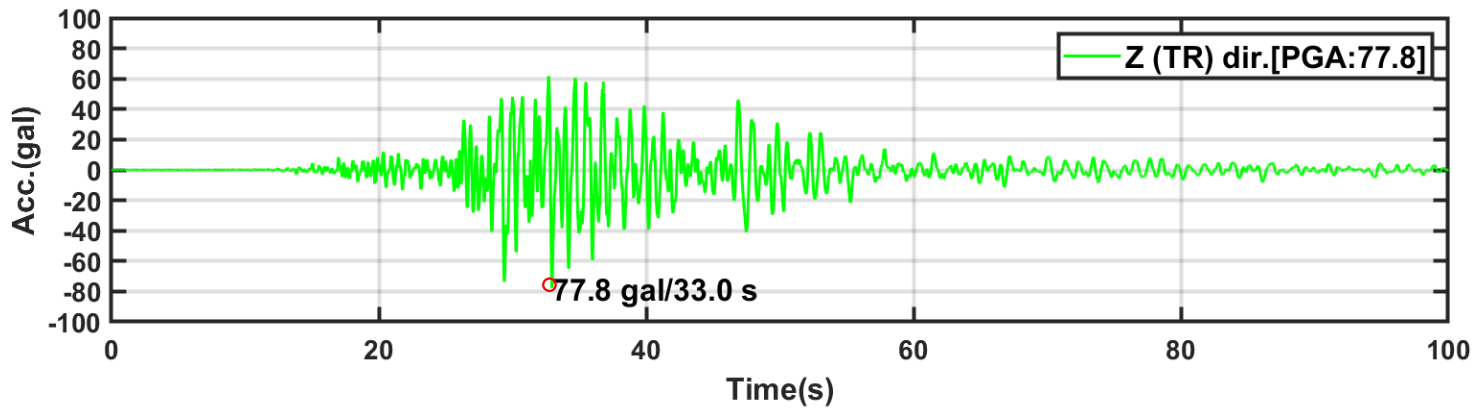


**2024/04/03**  
**Hualien Earthquake**  
**( $M_L = 7.2$ )**

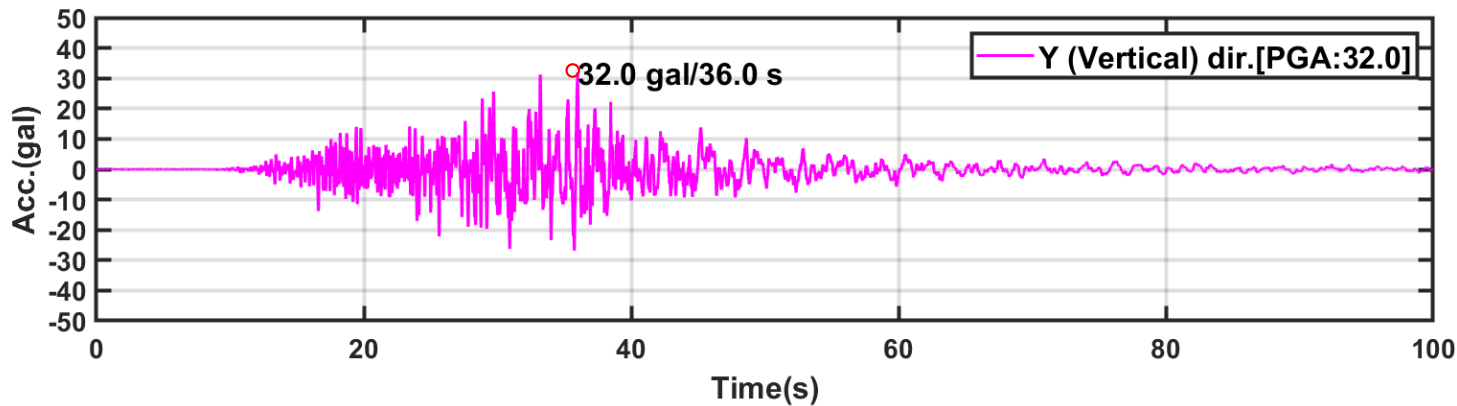
# Ground Motions of Seismic Event: E20240403T00001964 ( $M_L$ 7.2 Earthquake on 2024/04/03)



The averaged records were obtained from Channels 41 and 47 at **A** and **B**, respectively.

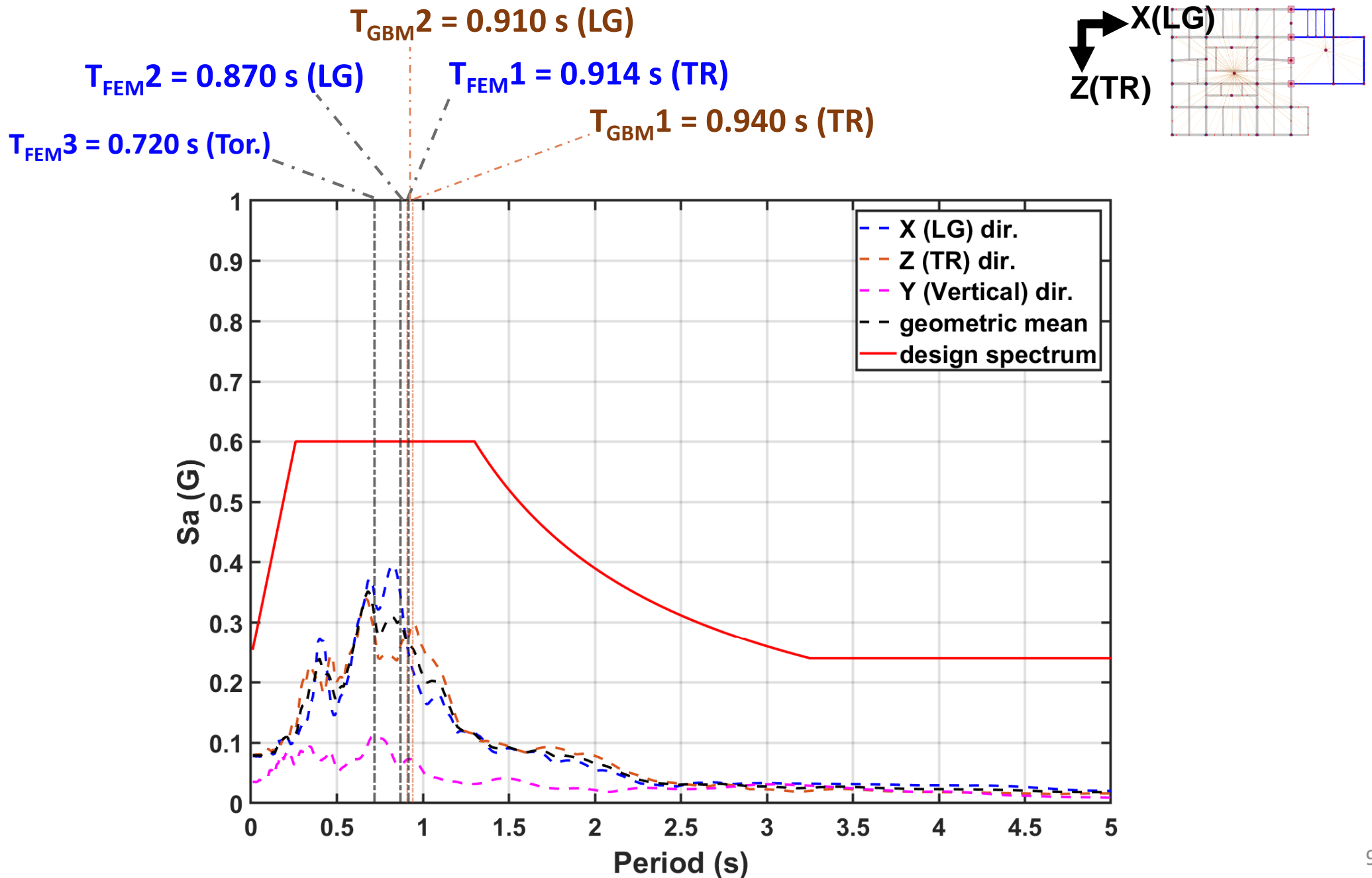


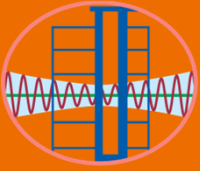
The averaged records were obtained from Channels 42 and 45 at **A** and **C**, respectively.



The records were obtained from Channel 40 at **D**.

# 5% Damped Acceleration Response Spectra





# Post-earthquake Response Estimation

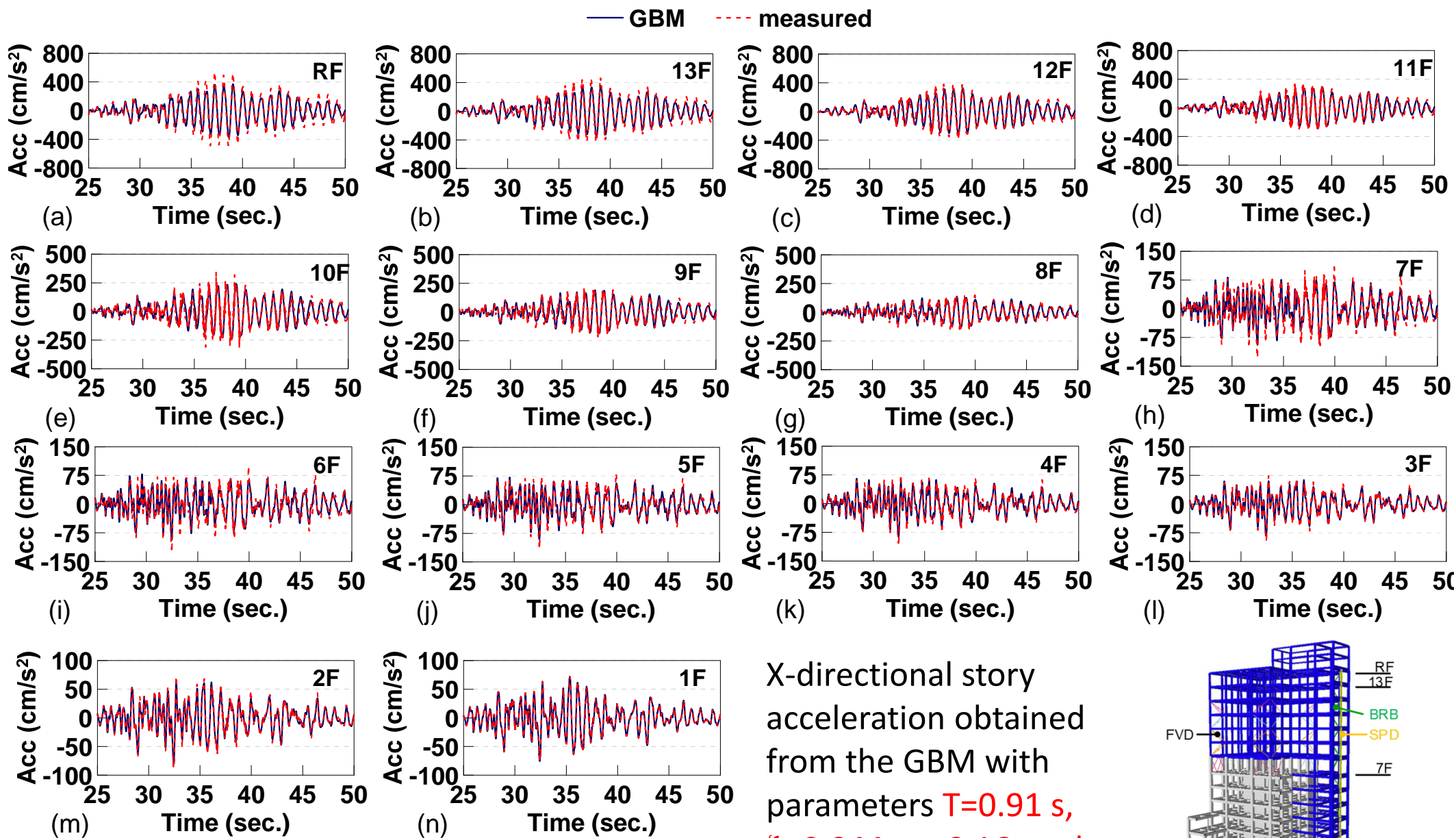


# Numerical Models Constructed Using PISA3D

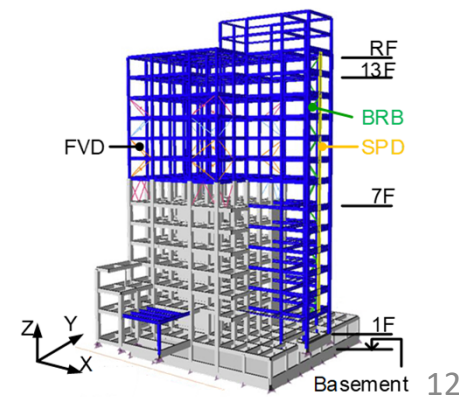
Model		Generalized Building Model (GBM)	Finite Element Model (FEM)
Response History Analysis (RHA)		Two-dimensional	Three-dimensional
Number of elements		26	2,995
Degrees of freedom		26	9,242
<b>Time consumption</b> (Integrator: Non-iterative Newmark scheme, Time length: 100 s, Step length: 0.005 s, Total steps: 20,000)		~5 seconds	~3 hours
Natural periods	1 <sup>st</sup> mode	0.94 s (TR)	0.914 s (TR)
	2 <sup>nd</sup> mode	0.91 s (LG)	0.870 s (LG)
	3 <sup>rd</sup> mode	N.A.	0.720 s (TOR)

# RHA with GBM

## Acc. Histories in LG direction (X dir.)

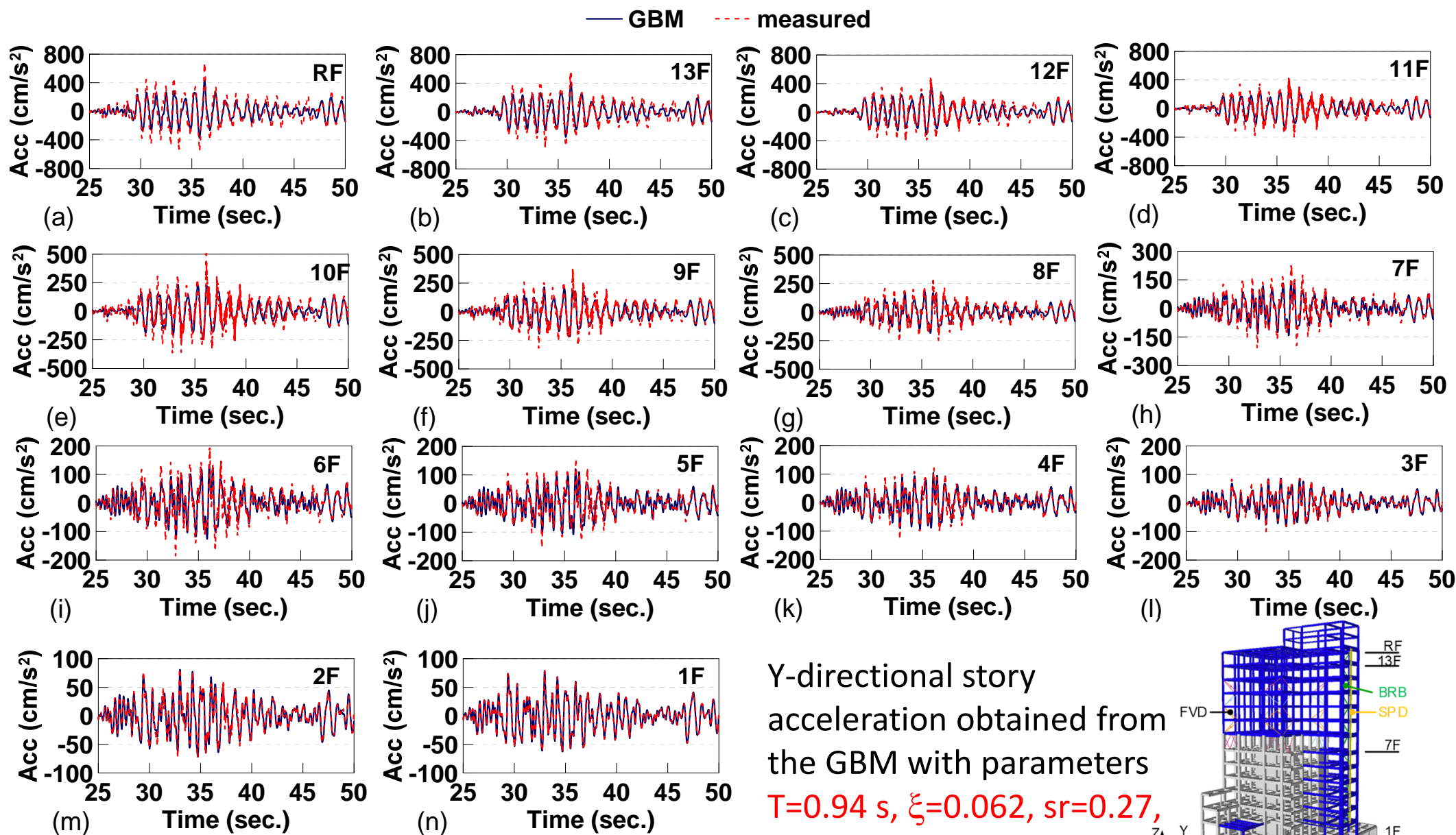


X-directional story acceleration obtained from the GBM with parameters  $T=0.91$  s,  $\xi=0.044$ ,  $sr=0.16$ , and  $\alpha=1.0$ .

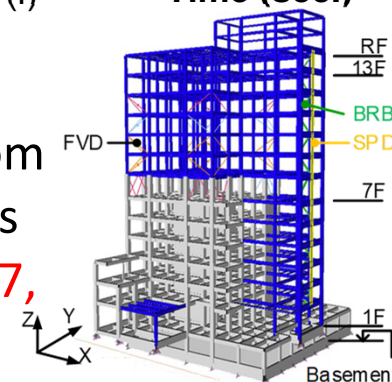


# RHA with GBM

Acc. Histories in TR direction (Y dir. of SSMS's coordinate)

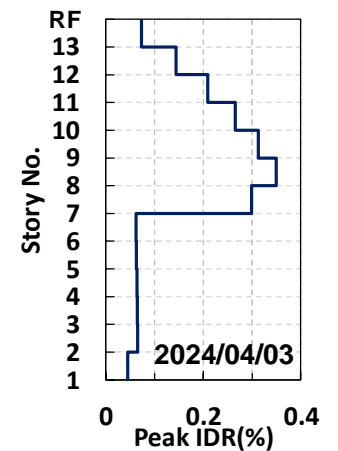
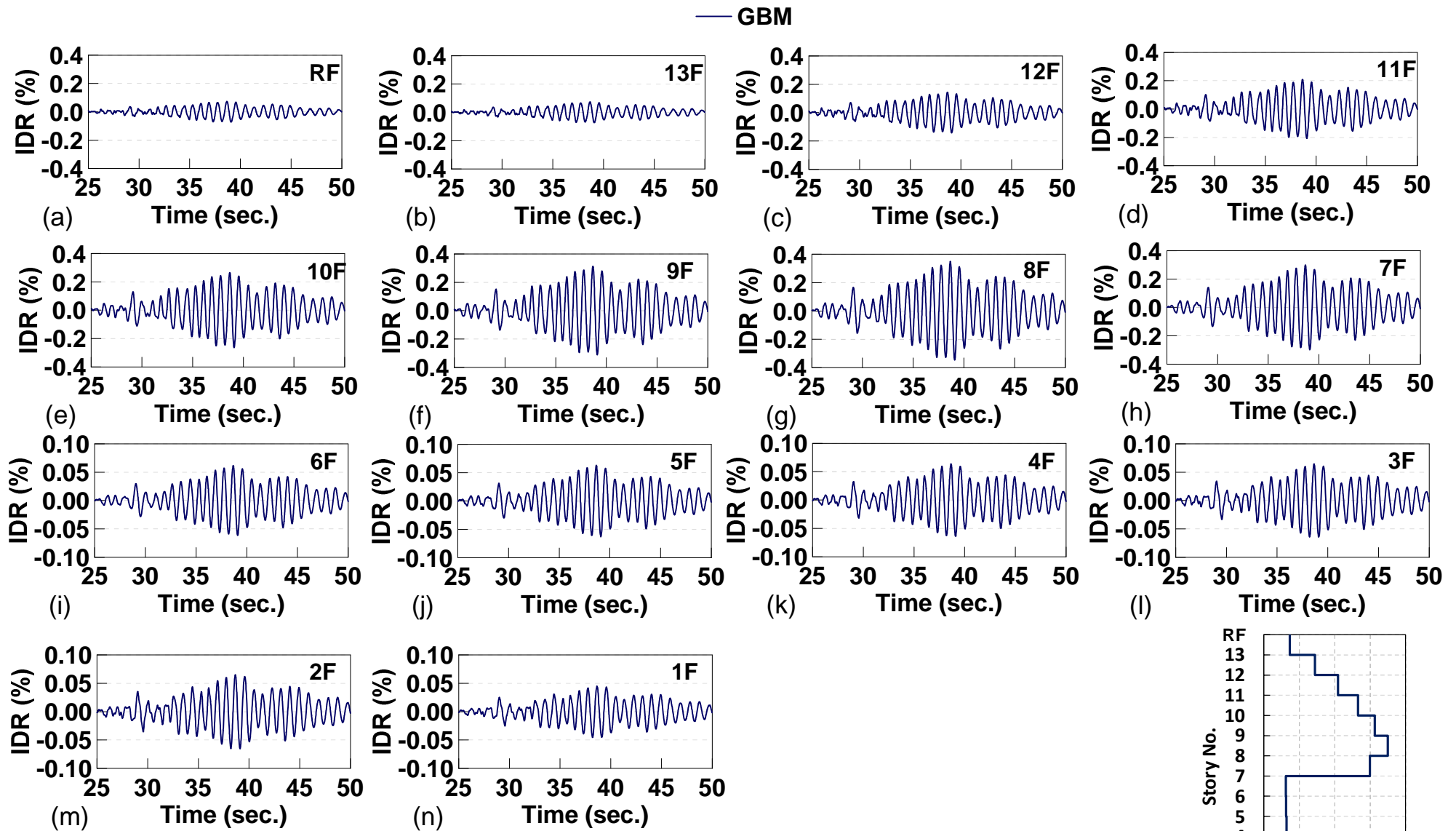


Y-directional story acceleration obtained from the GBM with parameters  $T=0.94\text{ s}$ ,  $\xi=0.062$ ,  $sr=0.27$ , and  $\alpha=1.0$ .

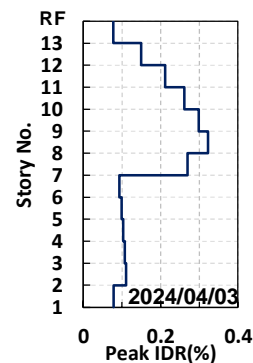
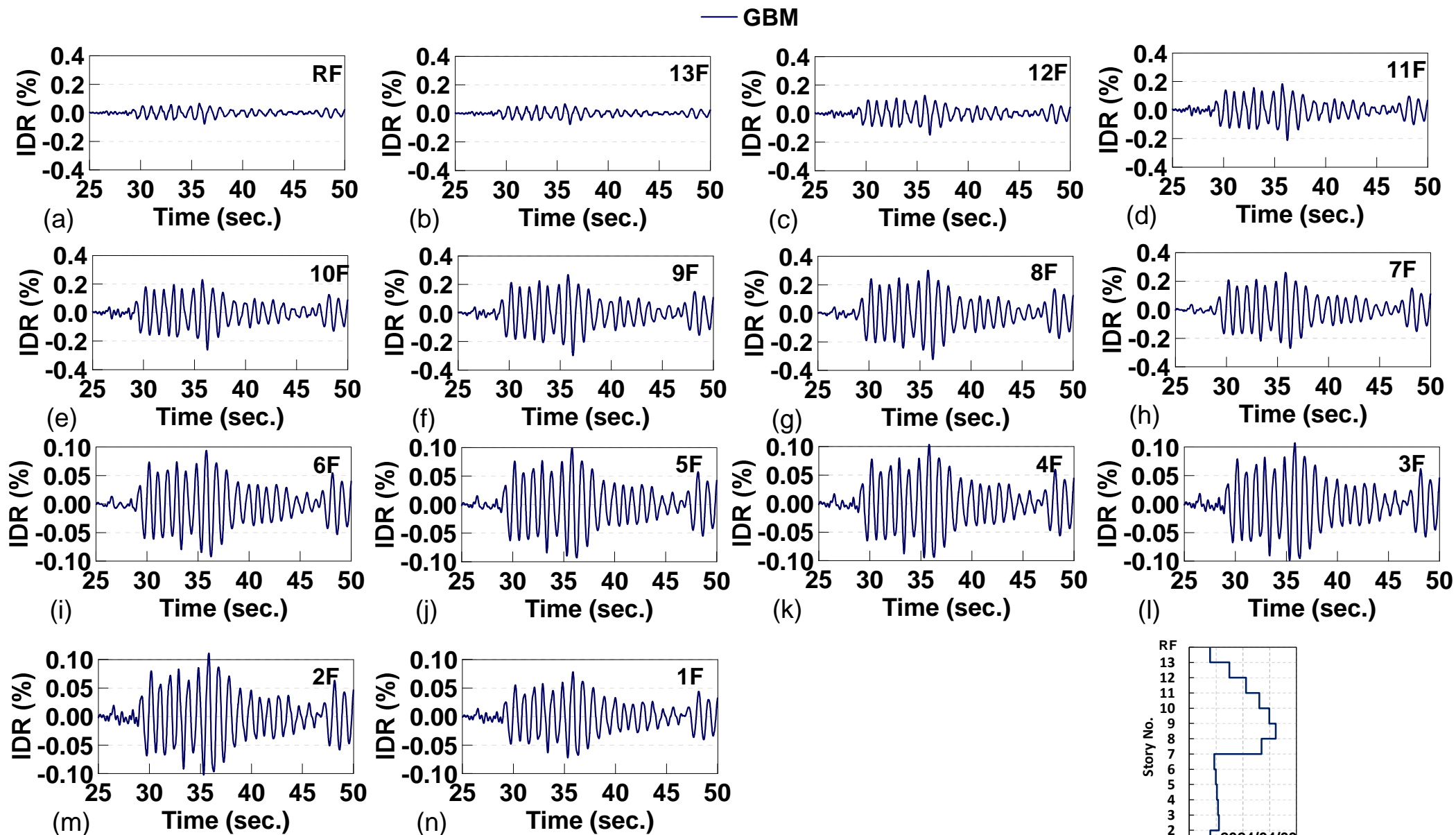


# RHA with GBM

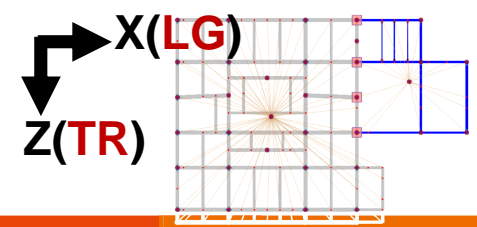
## Inter-story drift ratios in LG direction (X dir.)



## Inter-story drift ratios in TR direction (Y dir. of SSMS's coordinate)



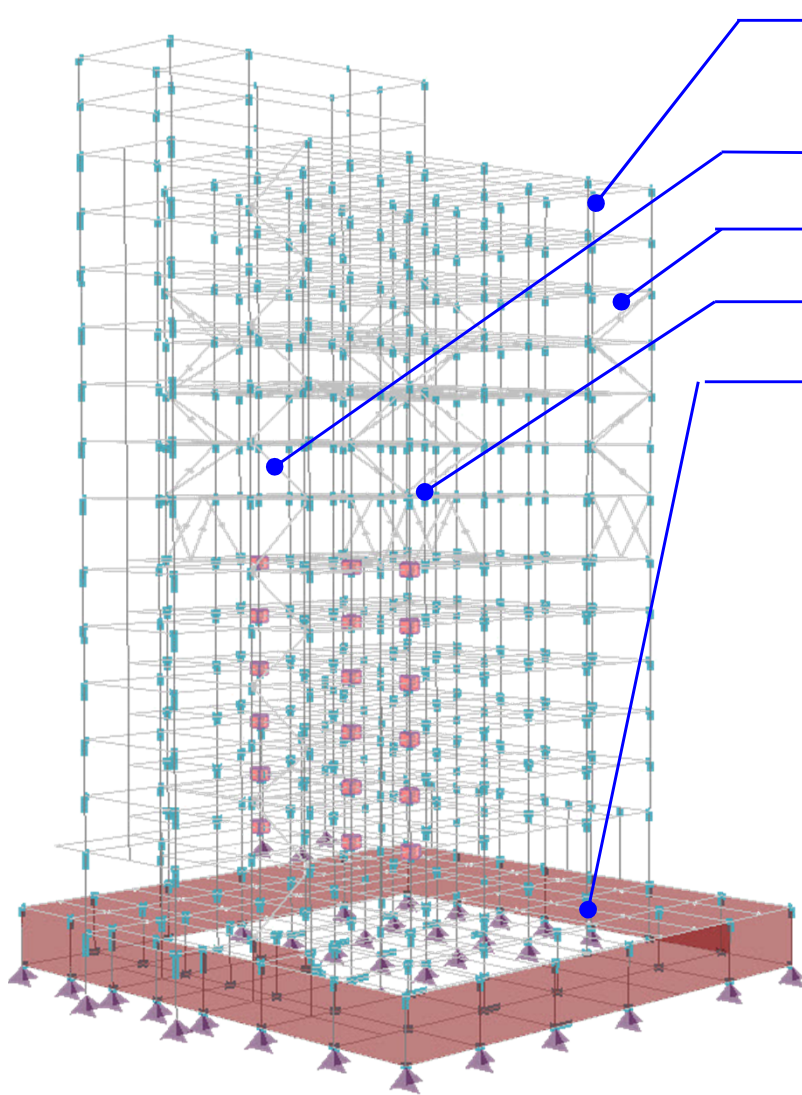
# Remarks on RHA with GBM



- The peak **LG(X)**-directional story accelerations recorded at 1F, 7F, and RF were 75.3, **124.7**, and **535.9** gal, respectively.
- The peak **TR(Z)**-directional story accelerations recorded at 1F, 7F, and RF were 79.6, **225.6**, and **673.4** gal, respectively.
- The identified parameter values of the **X**-directional GBM are  $T=0.91$  s,  $\xi=0.044$ ,  $sr=0.16$ , and  $\alpha=1.0$ .
- The identified parameter values of the **Z**-directional GBM are  $T=0.94$  s,  $\xi=0.062$ ,  $sr=0.27$ , and  $\alpha=1.0$ .
- The peak **X**-directional inter-story drift ratio of the building is estimated equal to **0.35%**, which occurred at the 8th floor.
- The peak **Z**-directional inter-story drift ratio of the building is estimated equal to **0.32%**, which occurred at the 8th floor.

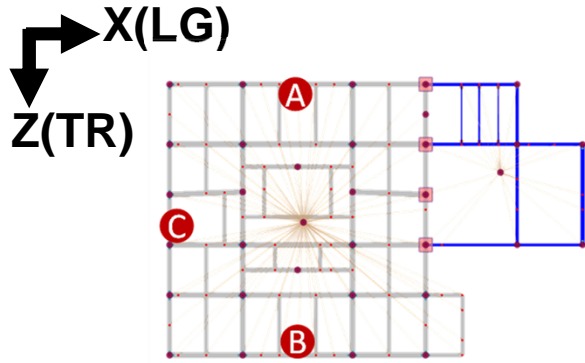


# FEM with PISA3D

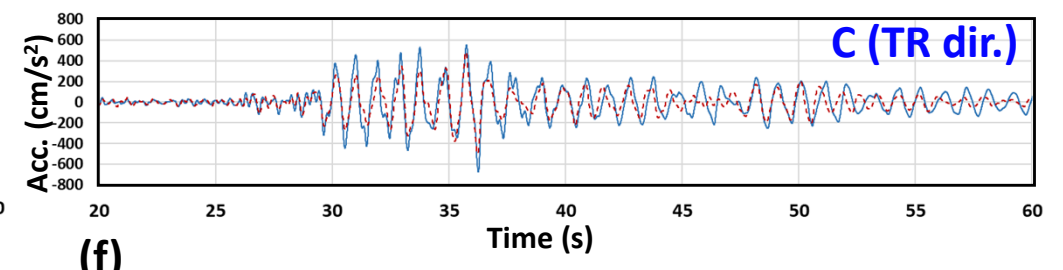
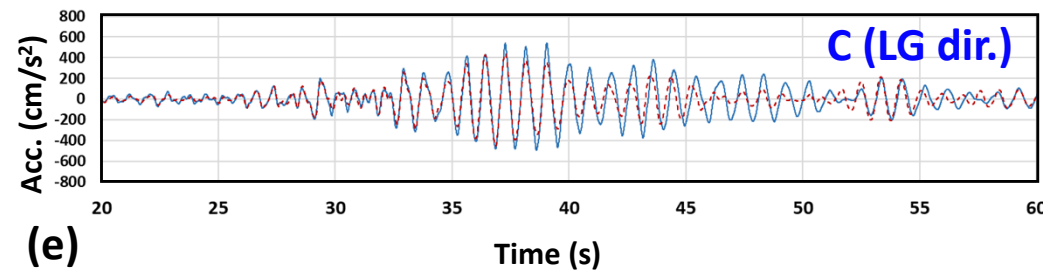
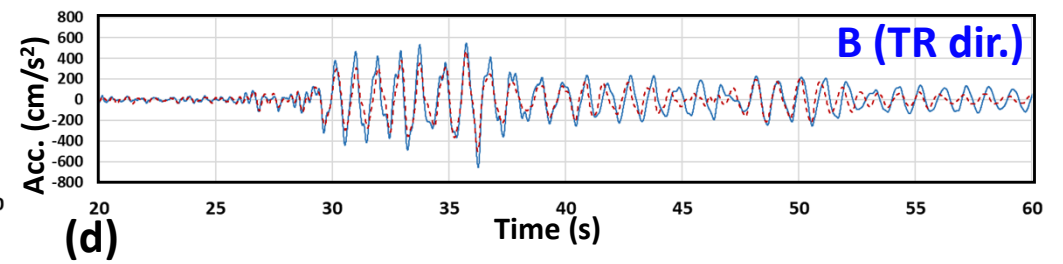
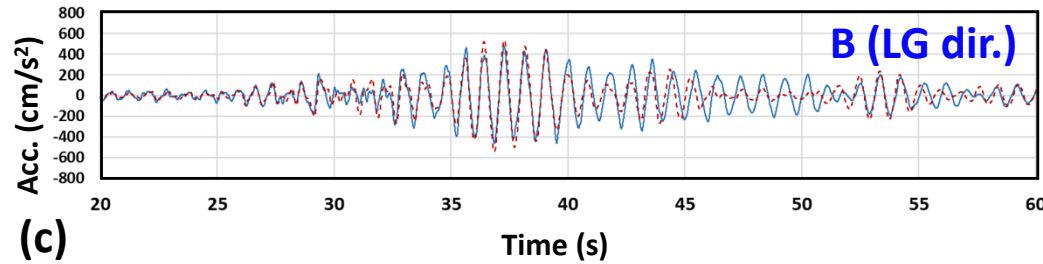
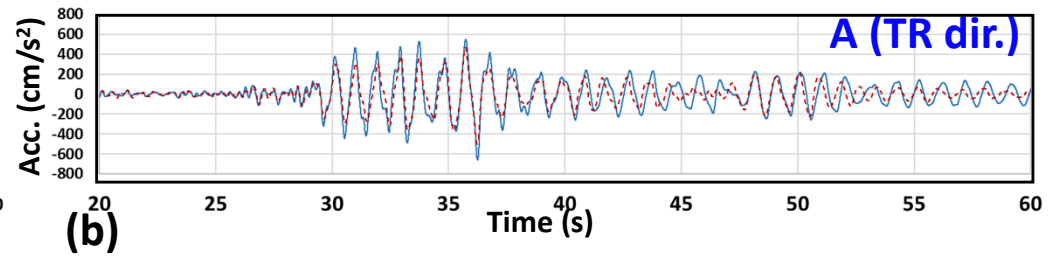
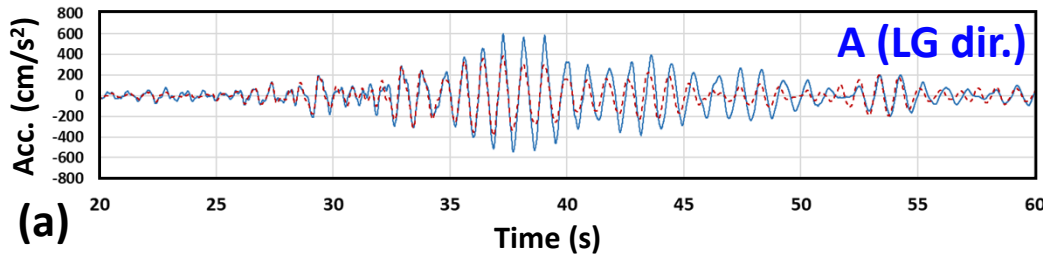


- **BeamColumn** elements for beams, columns, SPDs, and RC shear walls (wide-column model)
  - **Truss** element for BRBs
  - **Damper** elements for FVDs
  - **SixDJoint** elements for interface connections
  - **Panel** elements for RC walls of basement and window sills
  - Single and **dual rigid diaphragms**
  - Concentrated lateral lumped mass
  - Distributed vertical lumped mass
  - Reduced beam section (RBS) effects on column face
- **Full flexural and shear rigidities of beams, columns and walls**
  - **Incorporating the presence of window sills (intentionally elastic panel) and composite beam effects**
  - **Rayleigh damping: 3% for the 1st and 2nd modes**

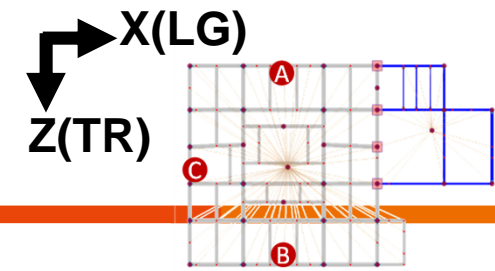
# Floor Acc. Histories of Roof



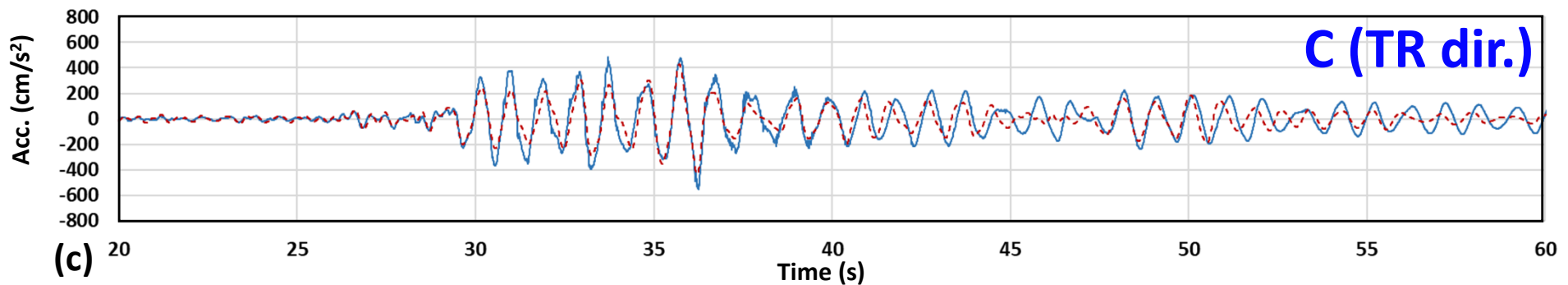
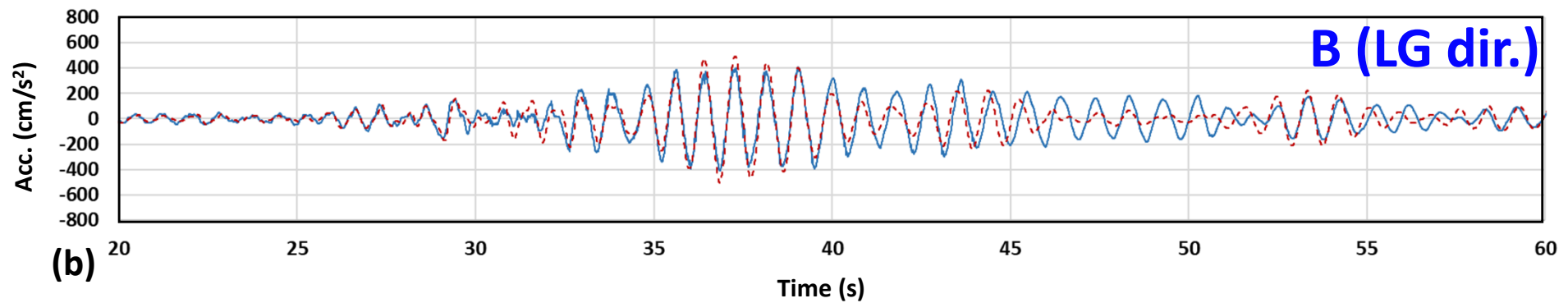
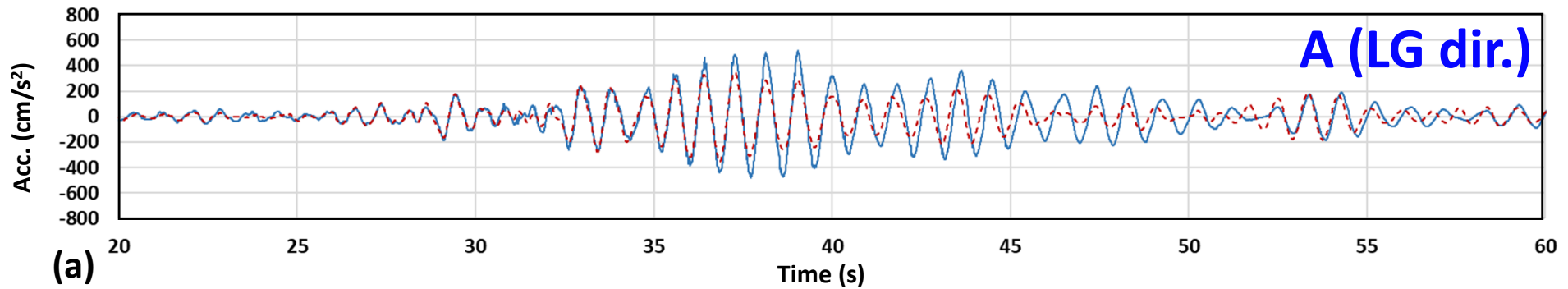
— Measured    - - - PISA3D



# Floor Acc. Histories of 13F

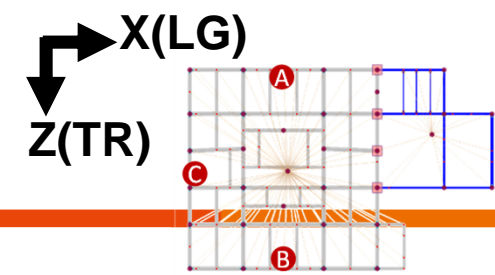


— Measured    - - - PISA3D

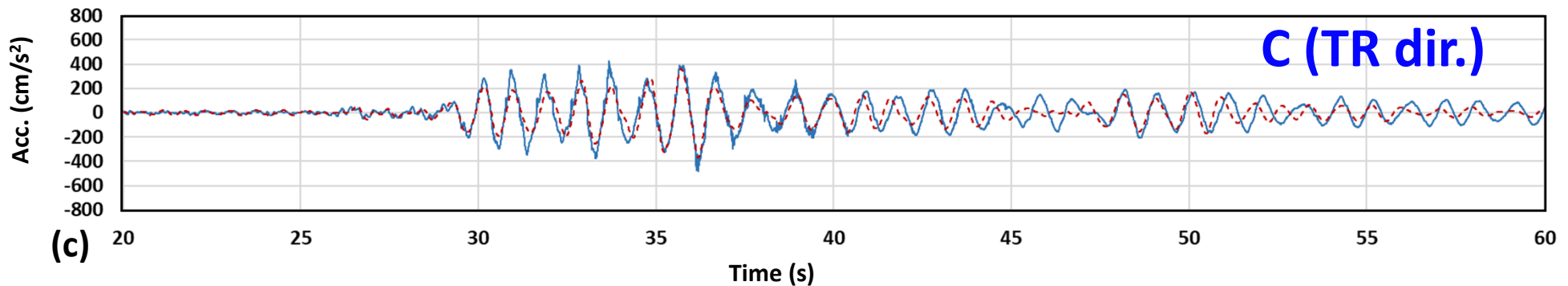
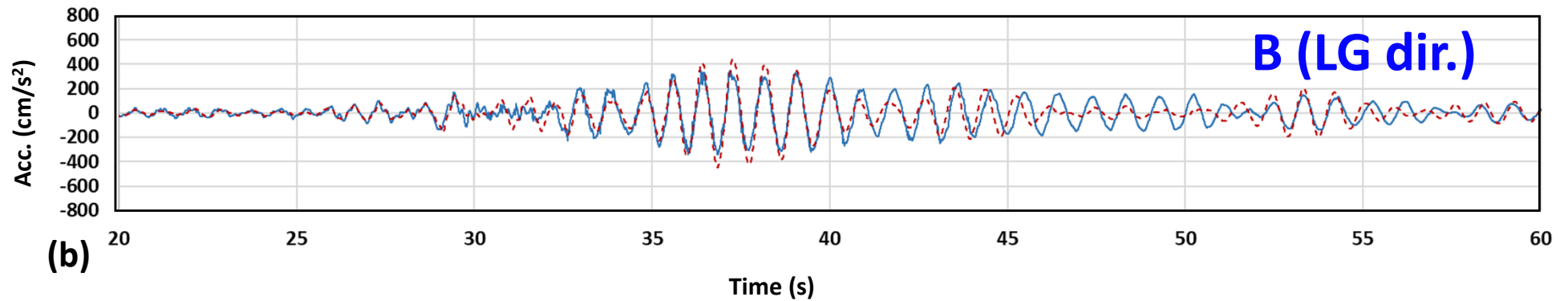
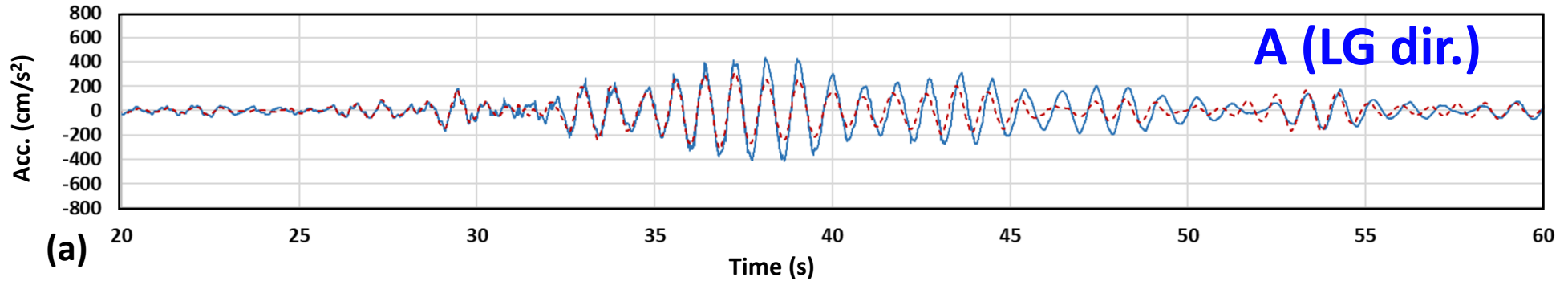


Number of Uniaxial Accelerometers (UA): 3

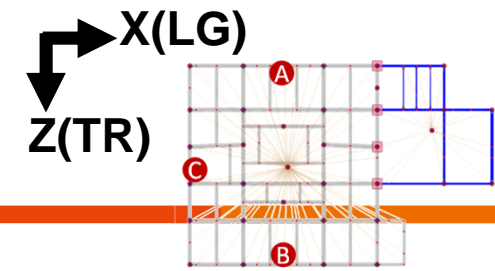
# Floor Acc. Histories of 12F



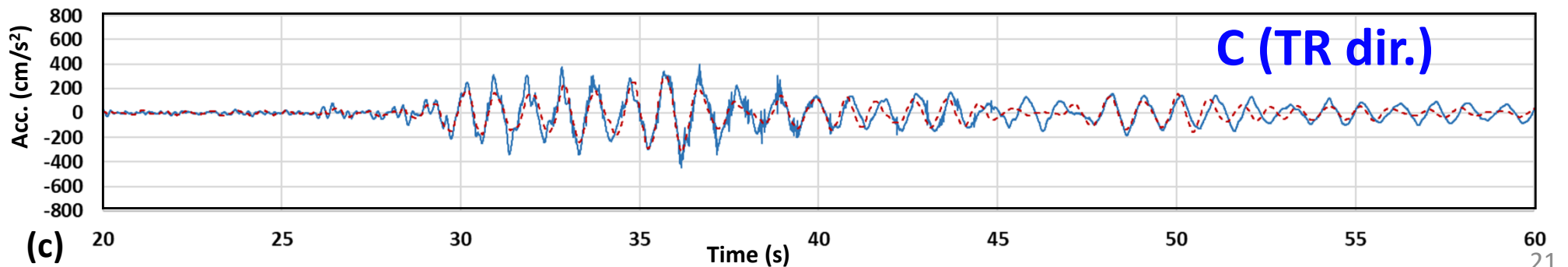
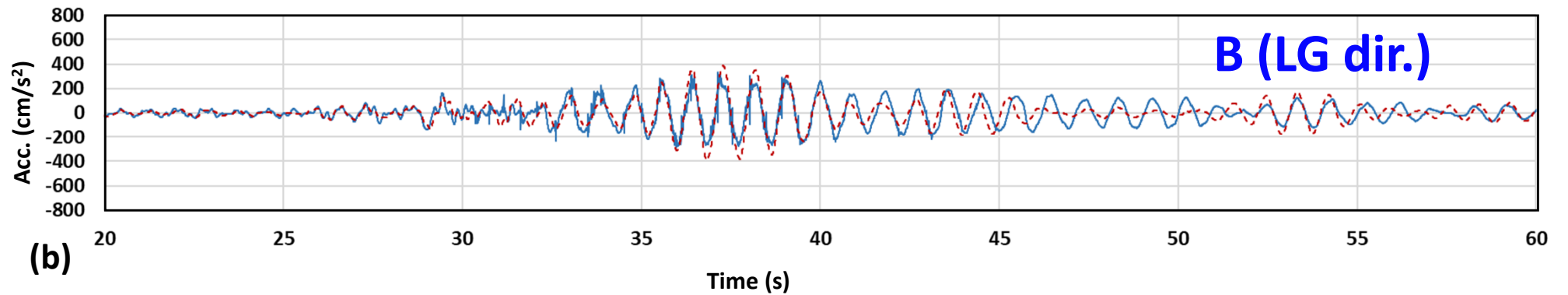
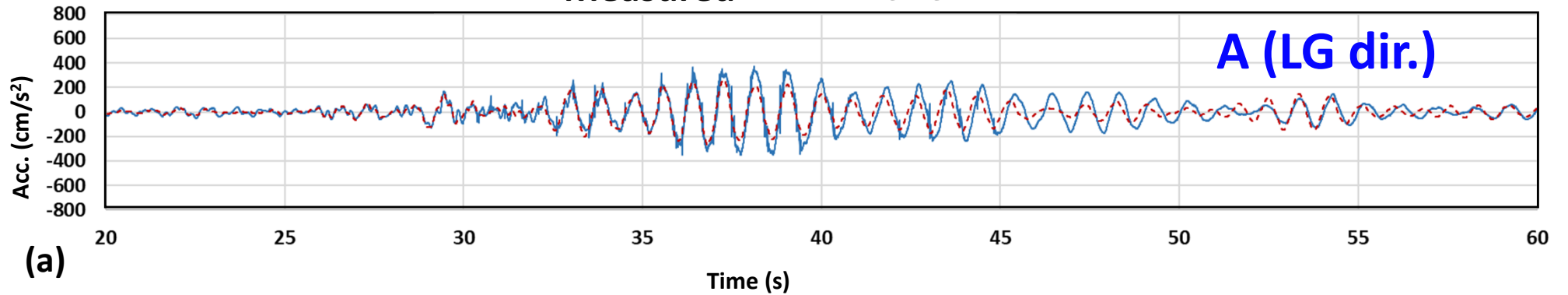
— Measured    - - - PISA3D



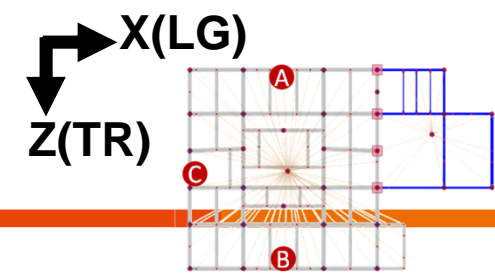
# Floor Acc. Histories of 11F



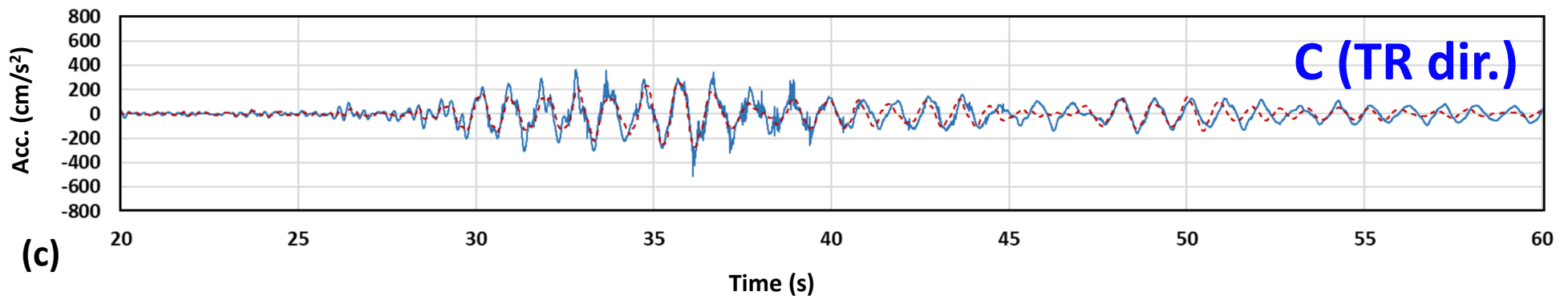
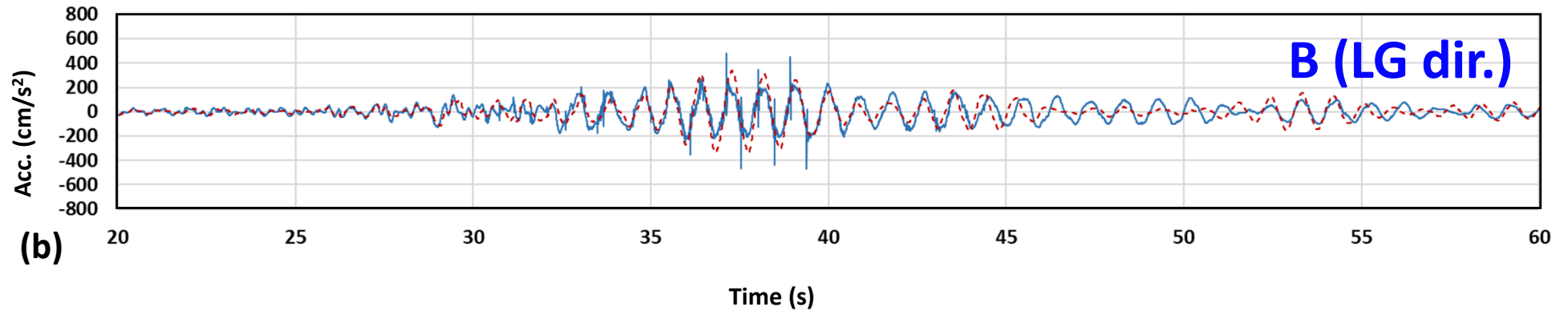
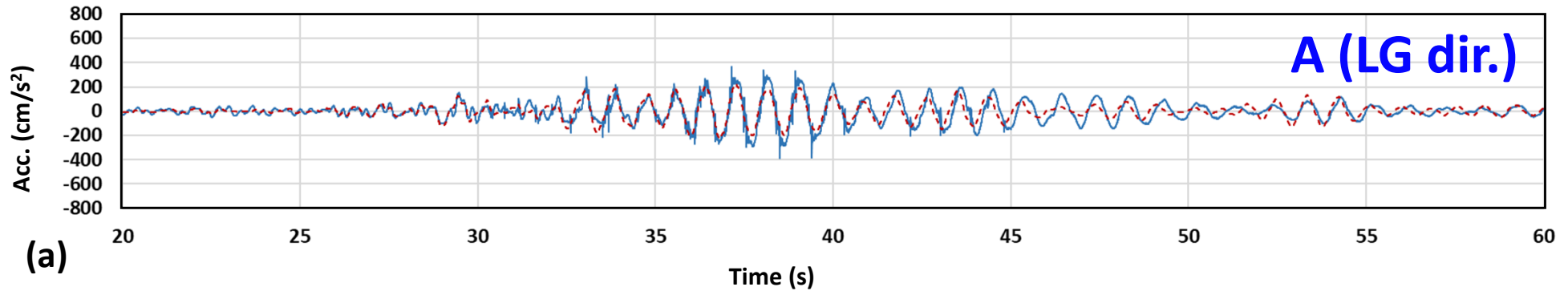
— Measured    - - - PISA3D



# Floor Acc. Histories of 10F

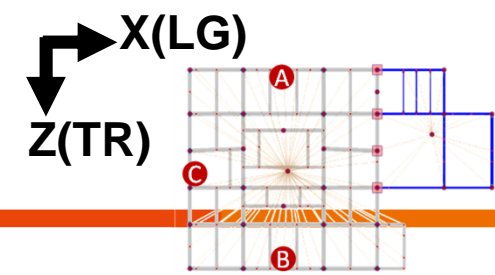


— Measured    - - - PISA3D

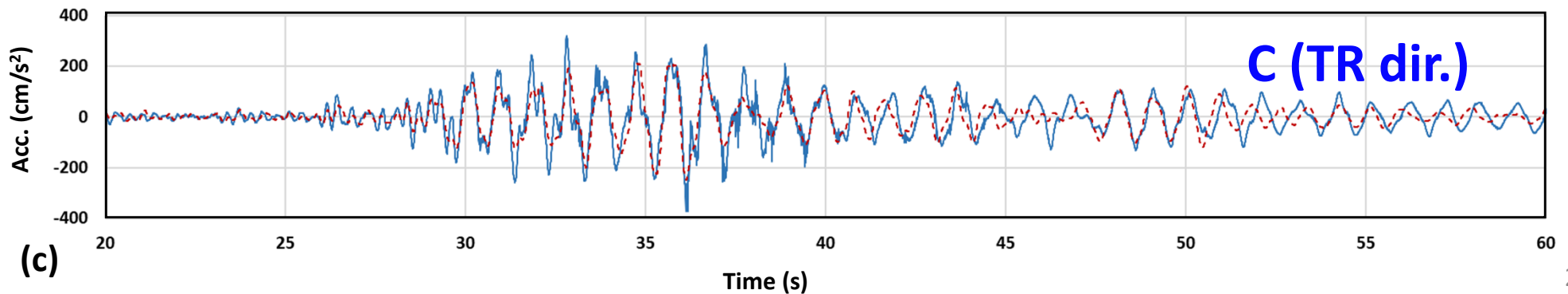
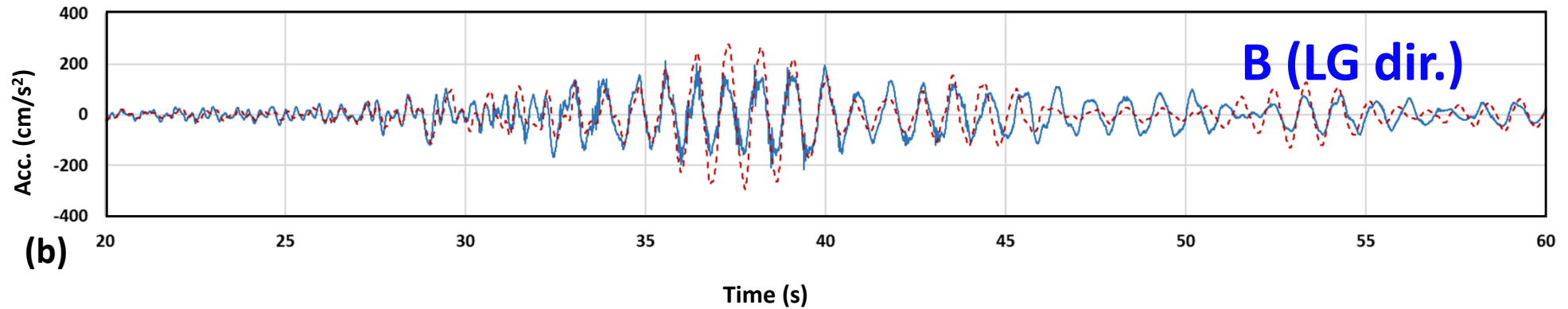
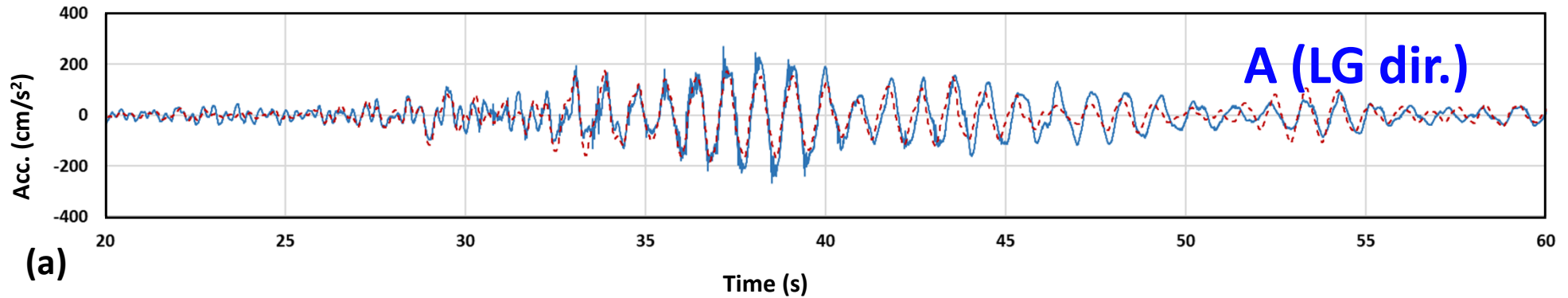




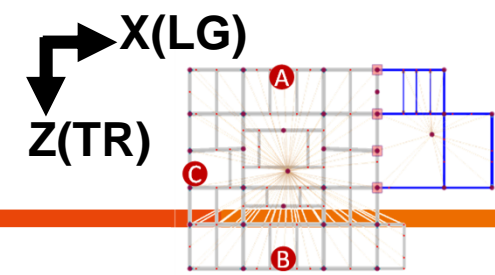
# Floor Acc. Histories of 9F



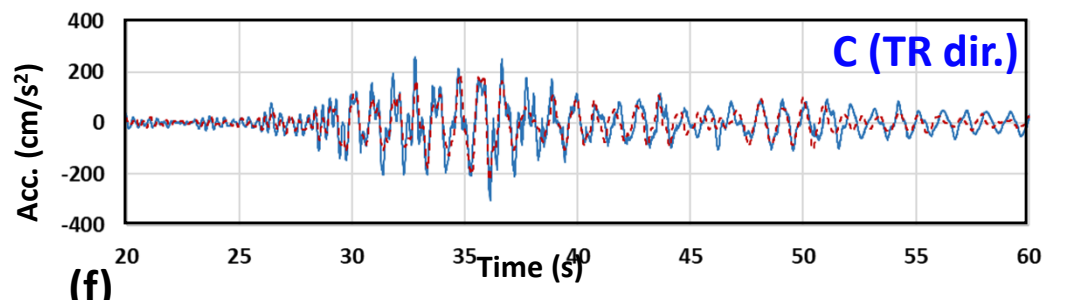
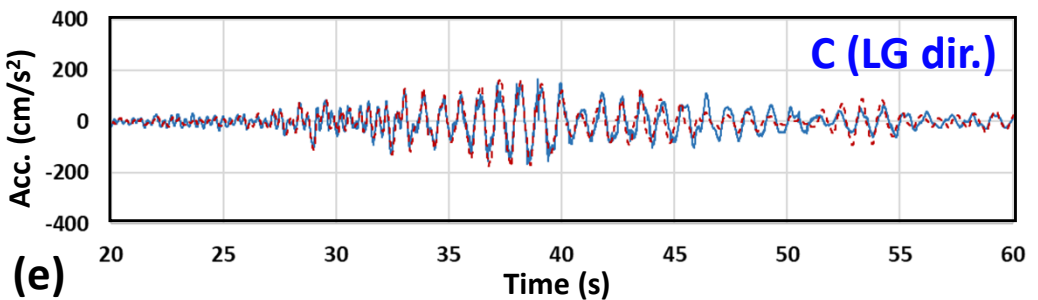
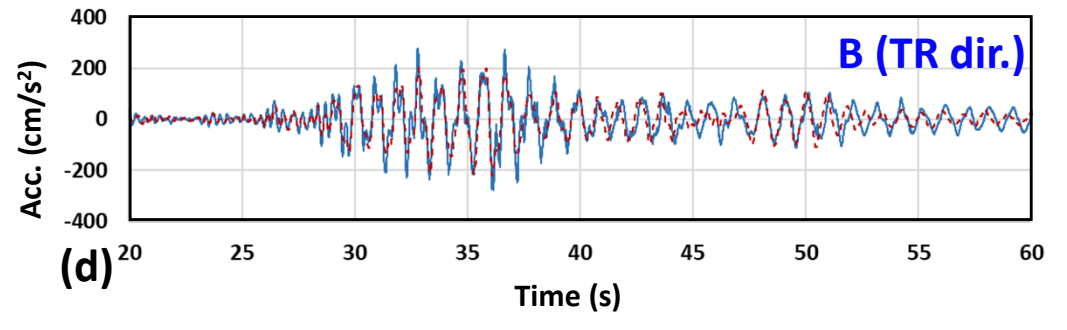
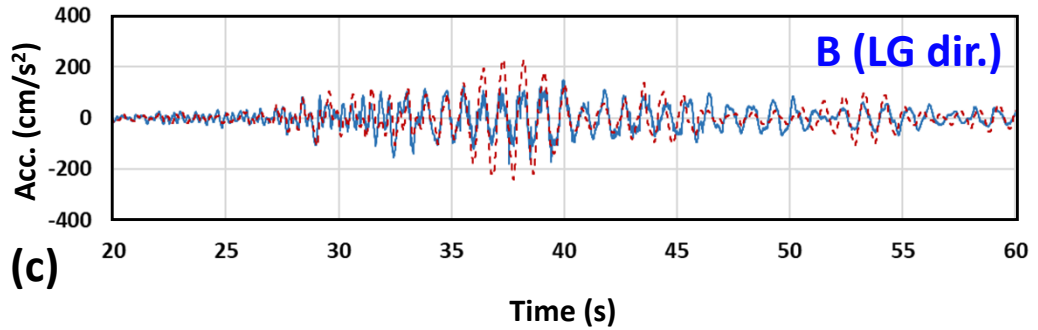
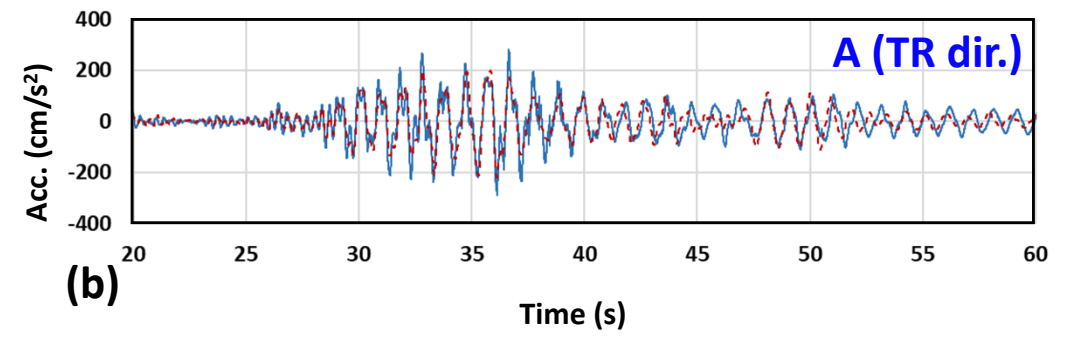
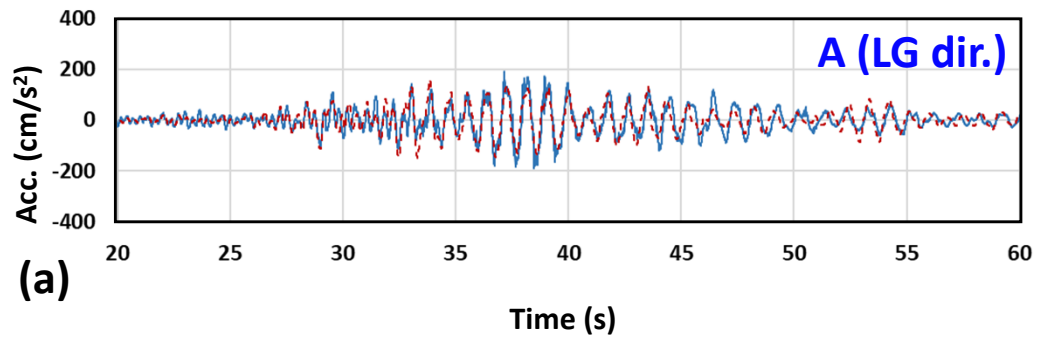
— Measured    - - - PISA3D



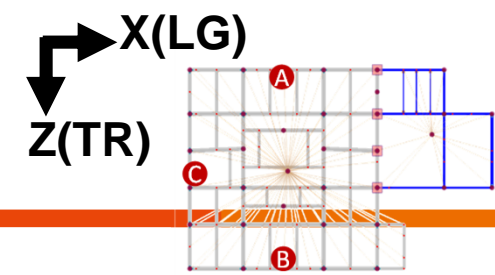
# Floor Acc. Histories of 8F



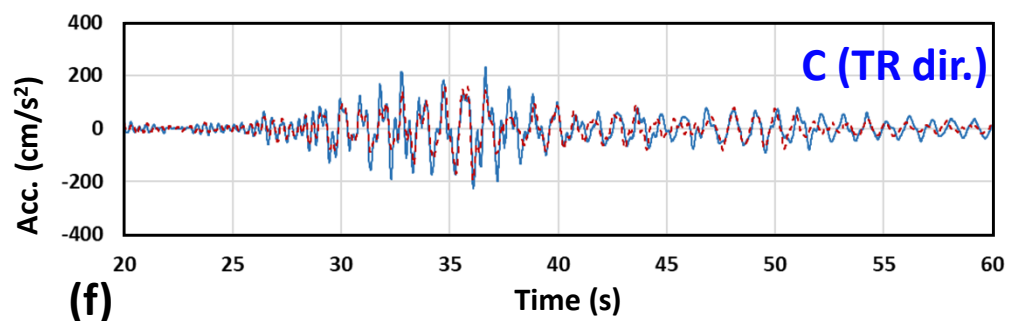
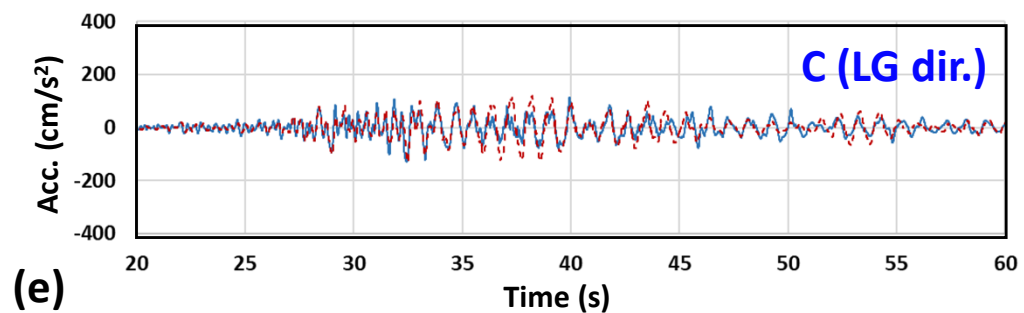
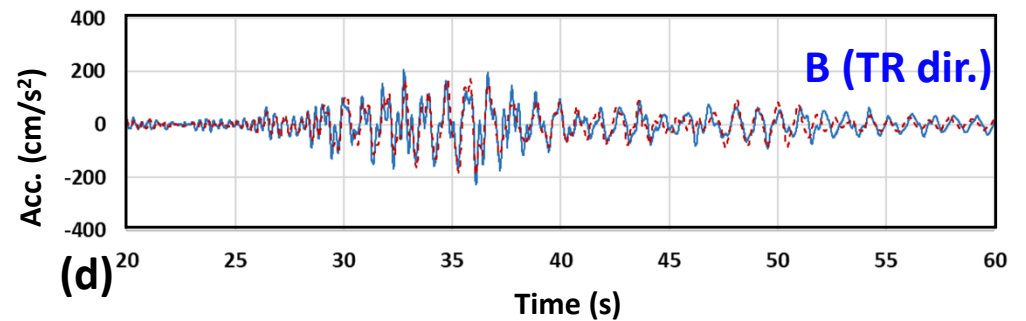
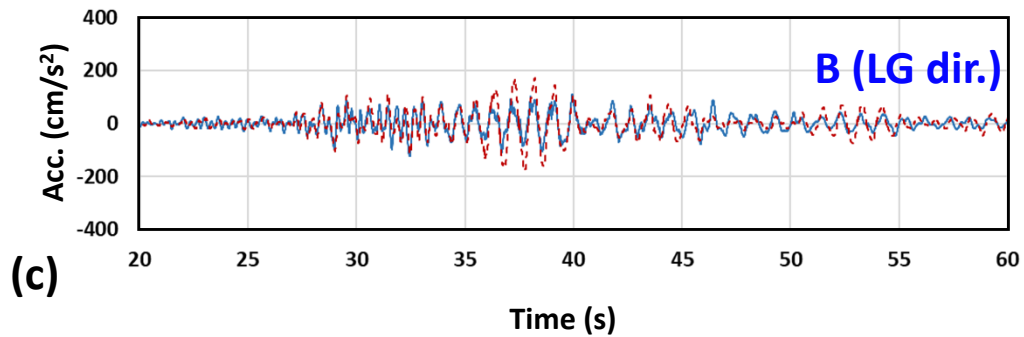
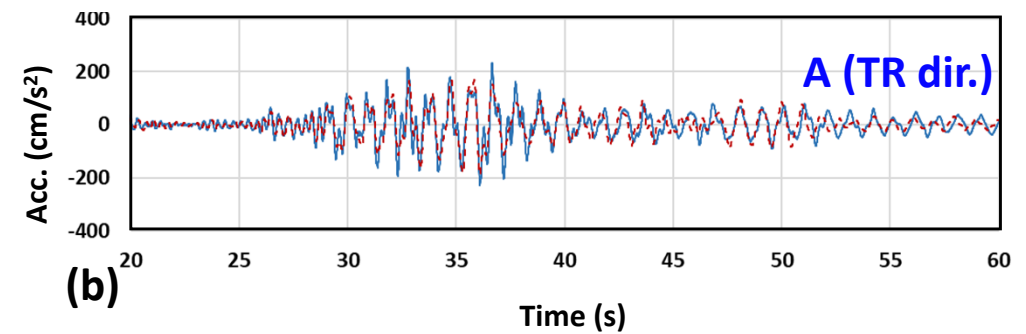
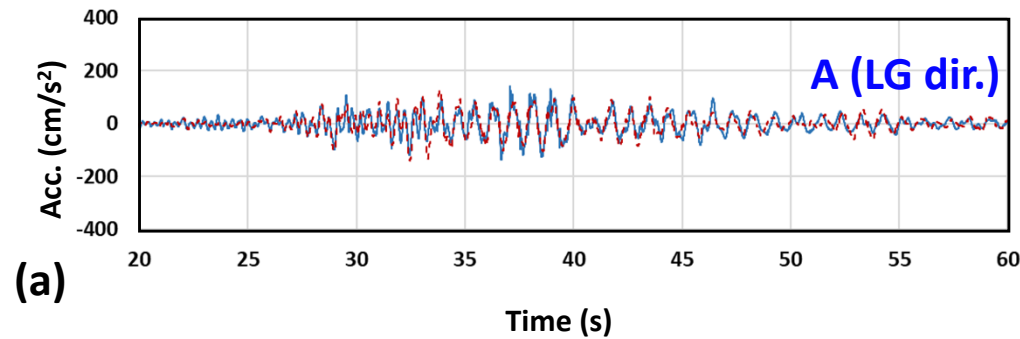
— Measured    - - - PISA3D



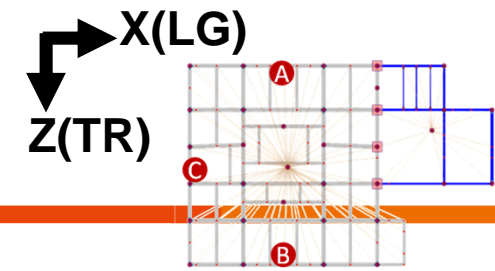
# Floor Acc. Histories of 7F



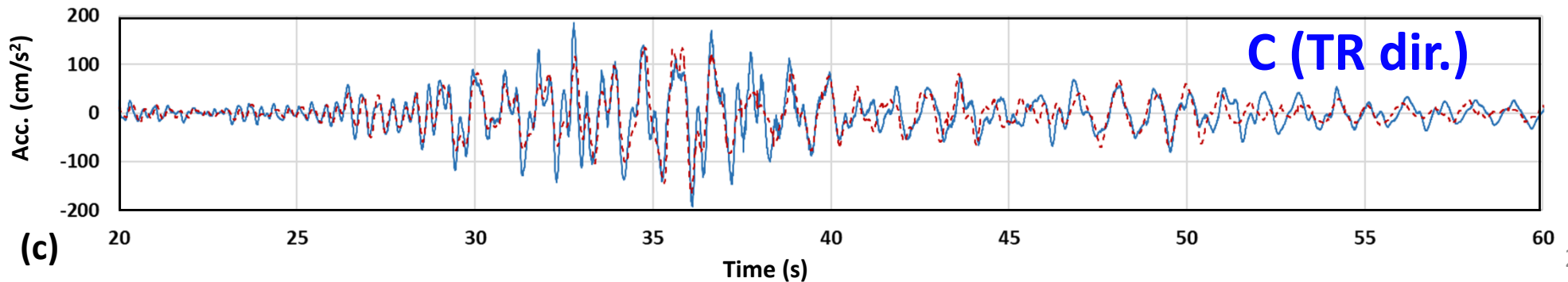
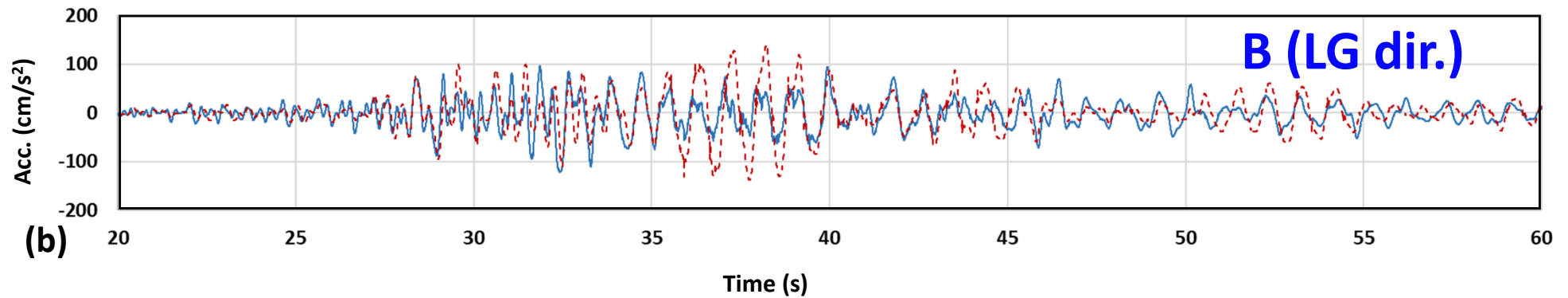
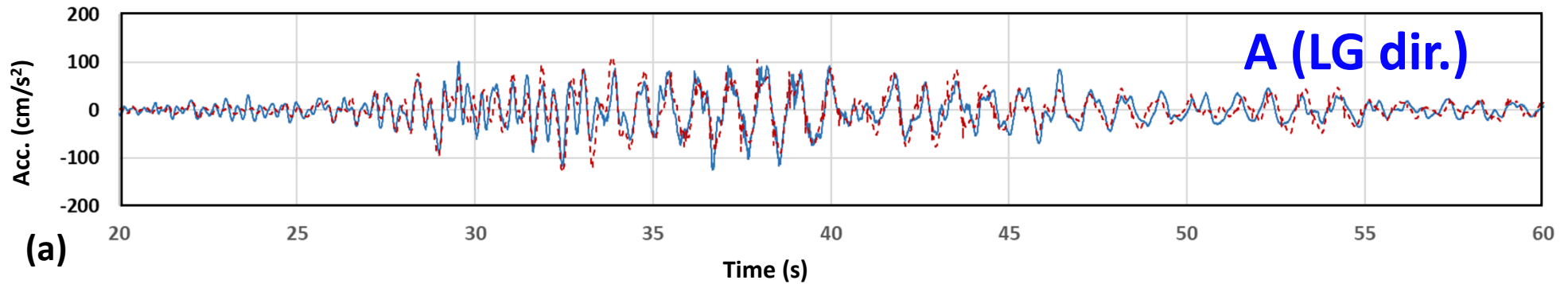
— Measured    - - - PISA3D



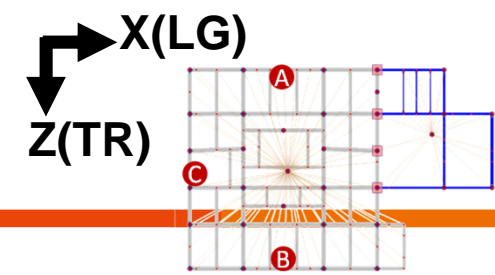
# Floor Acc. Histories of 6F



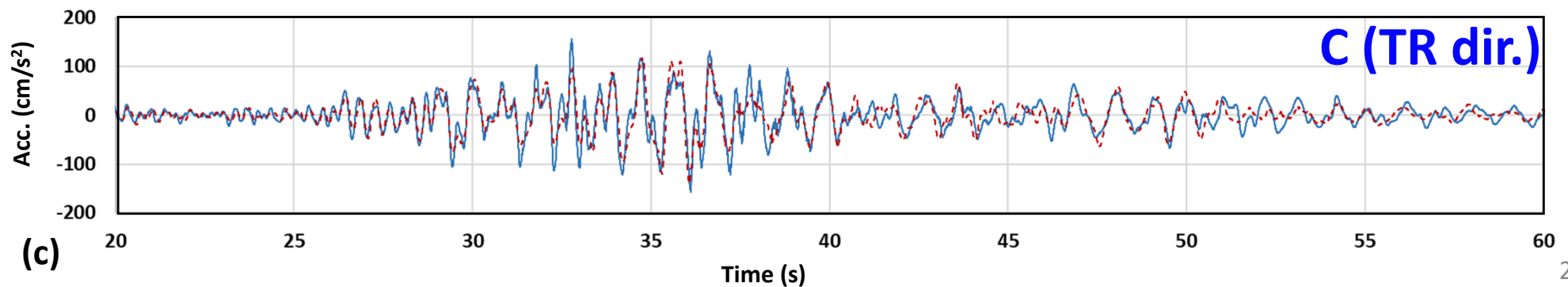
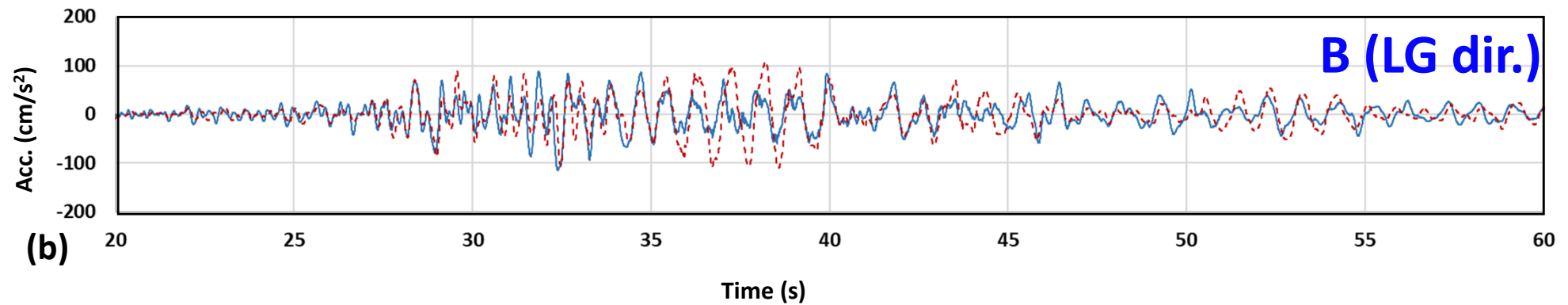
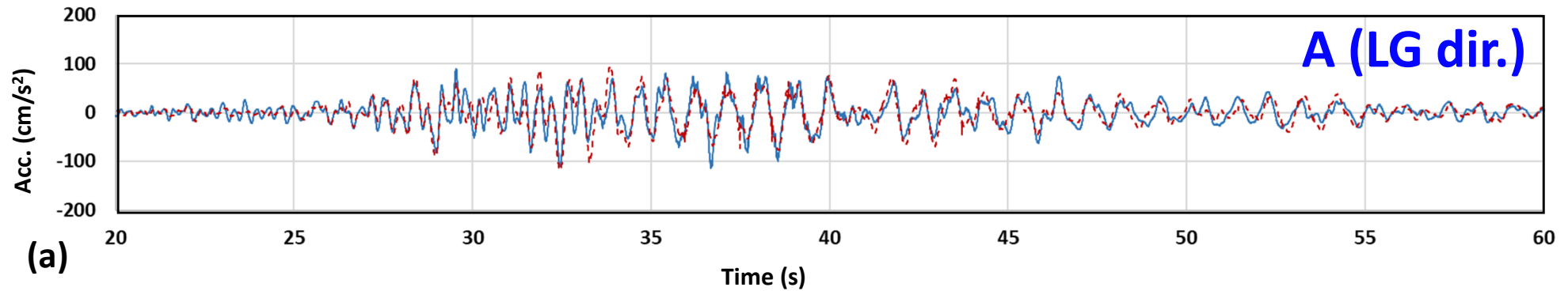
— Measured    - - - PISA3D



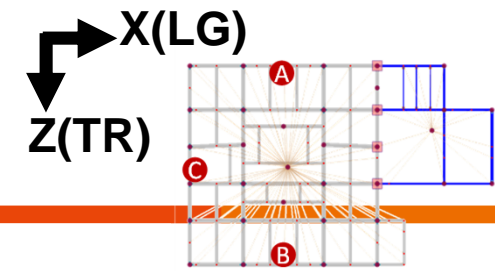
# Floor Acc. Histories of 5F



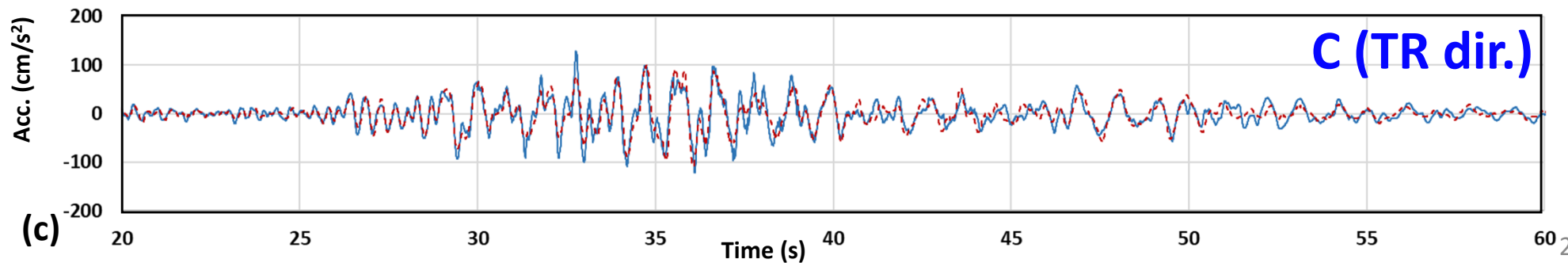
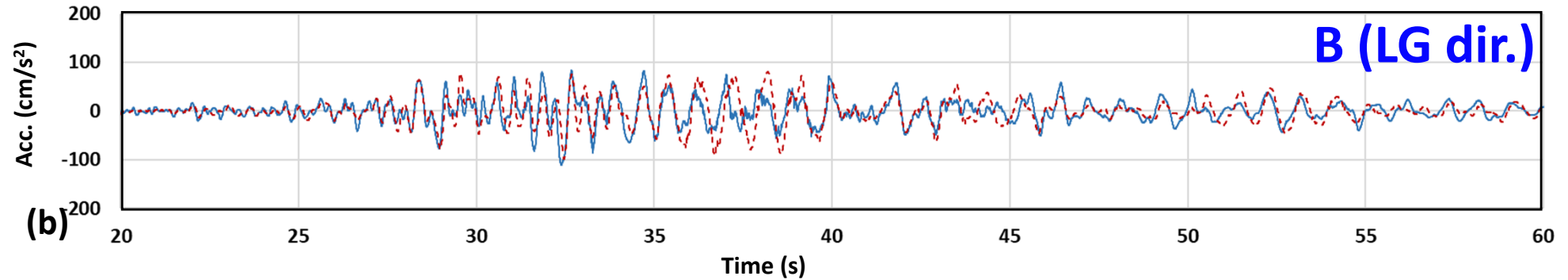
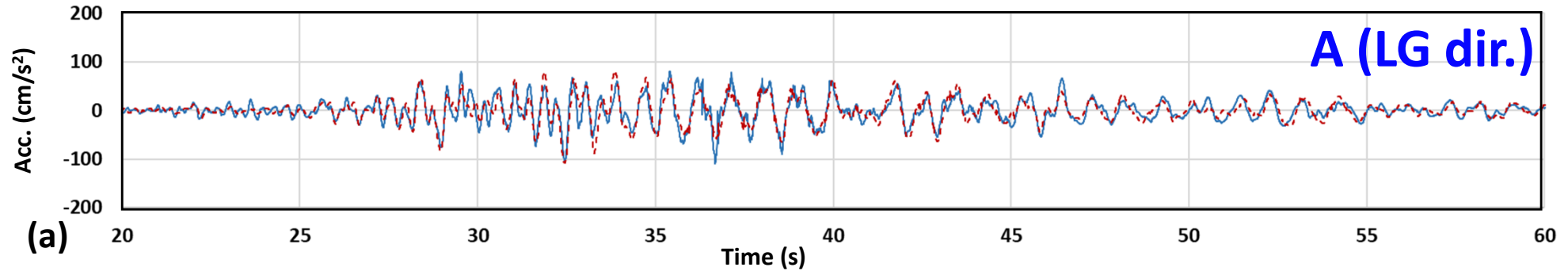
— Measured    - - - PISA3D



# Floor Acc. Histories of 4F

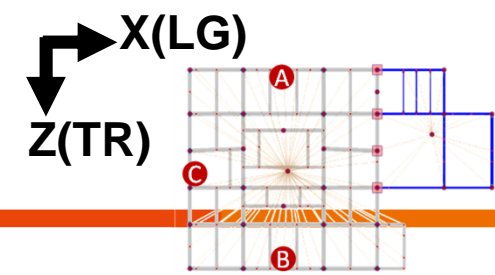


— Measured    - - - PISA3D

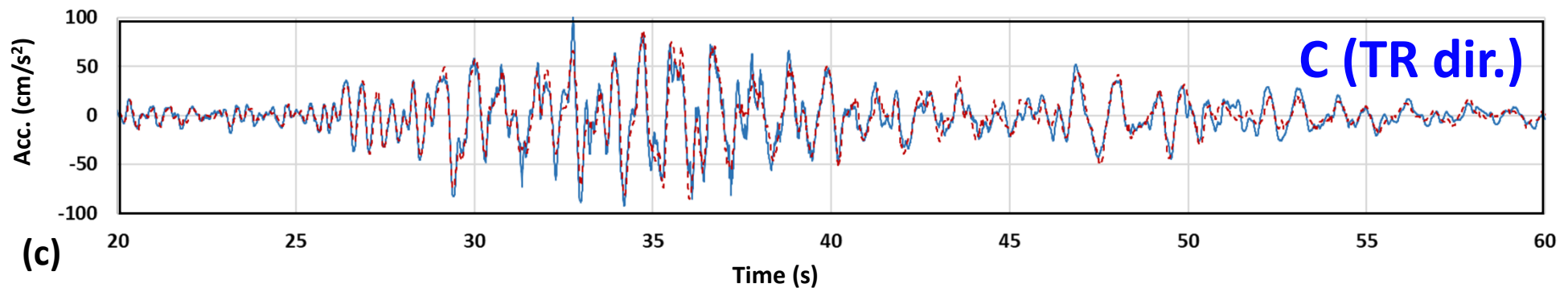
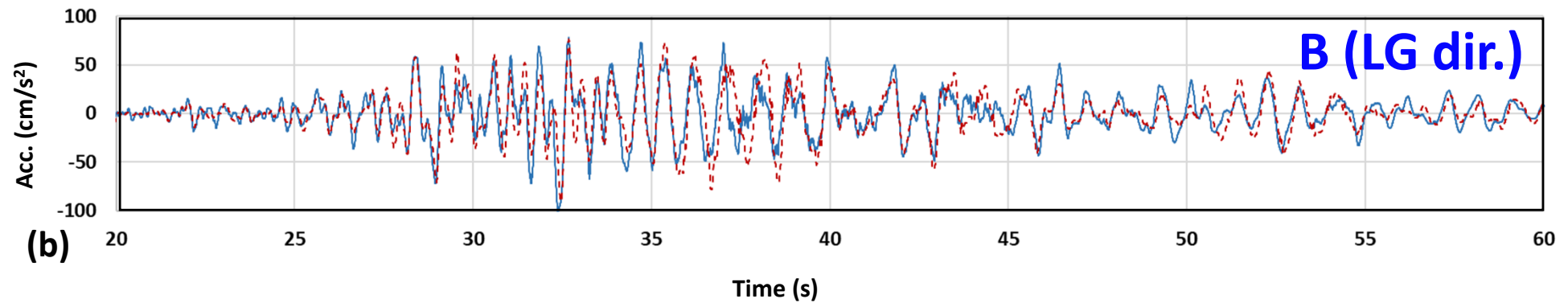
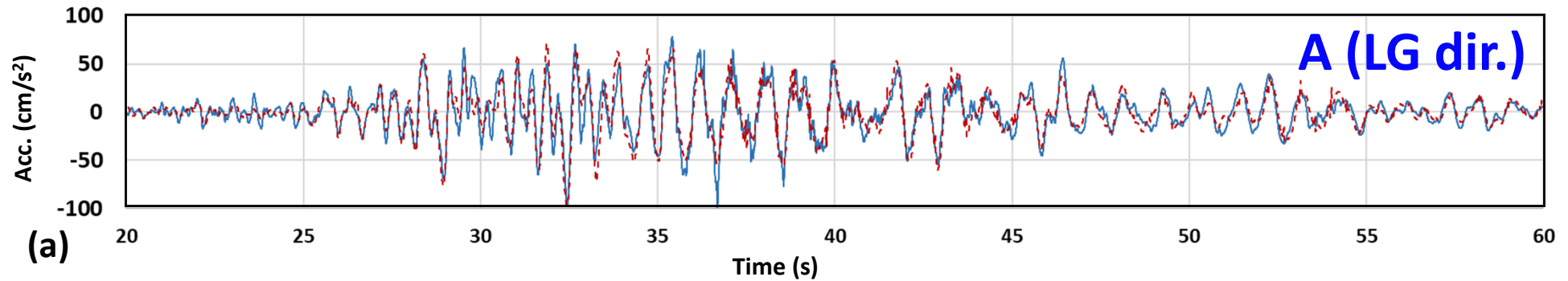




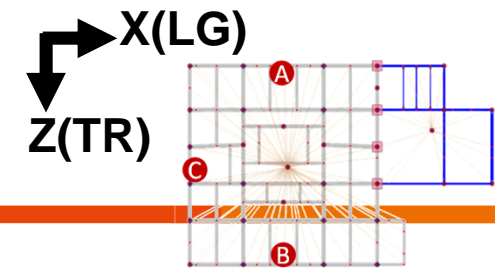
# Floor Acc. Histories of 3F



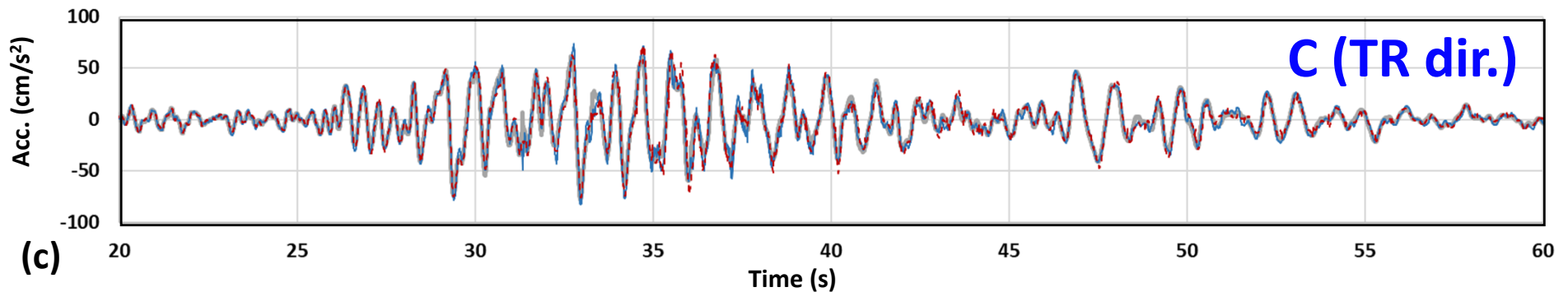
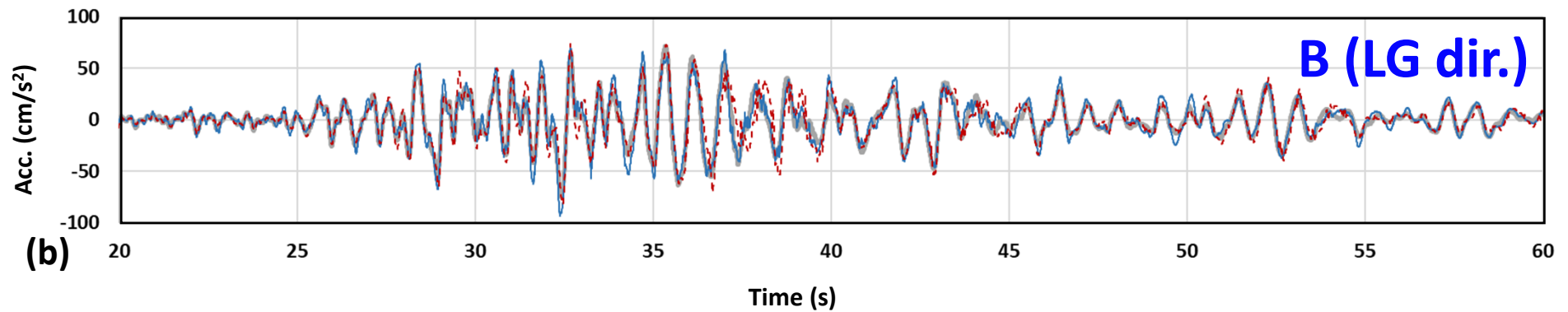
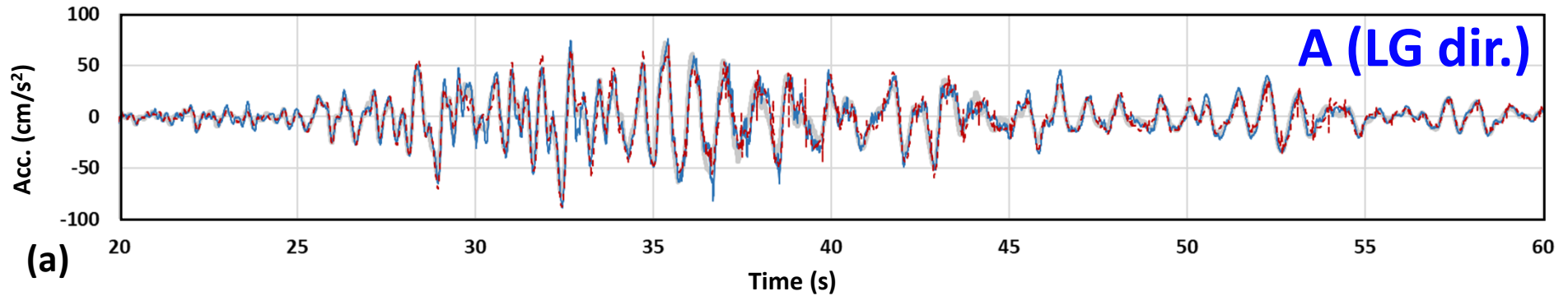
— Measured    - - - PISA3D



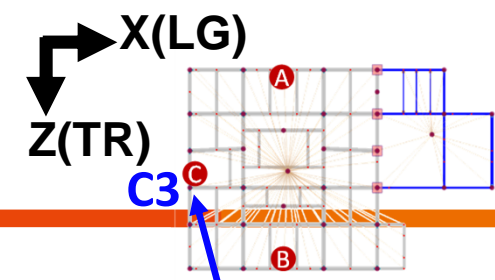
# Floor Acc. Histories of 2F



— Measured    - - - PISA3D    — Ground Motion

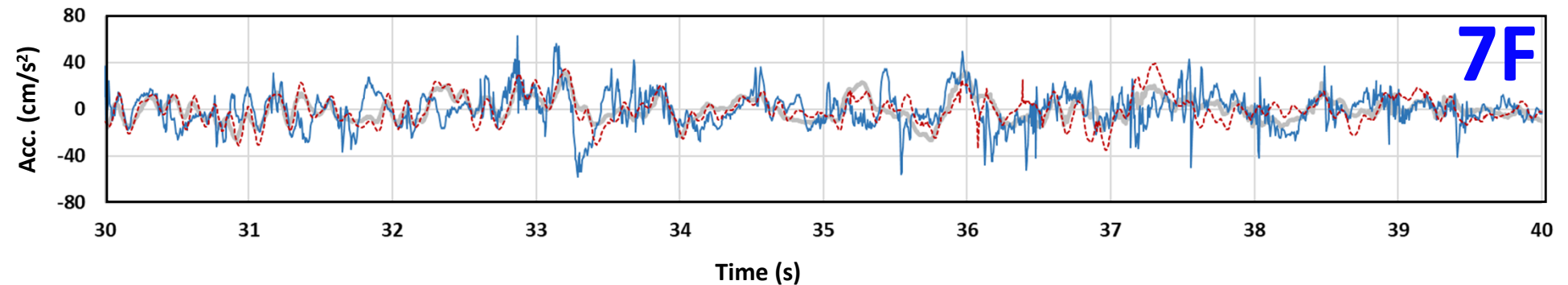
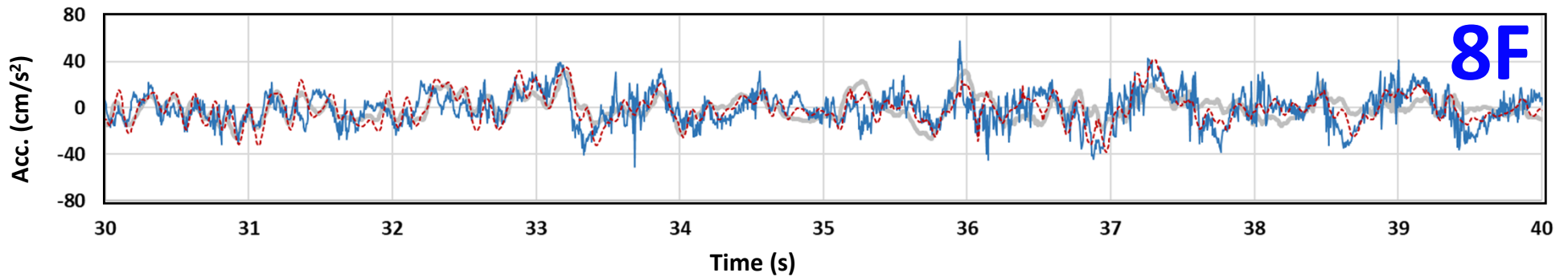
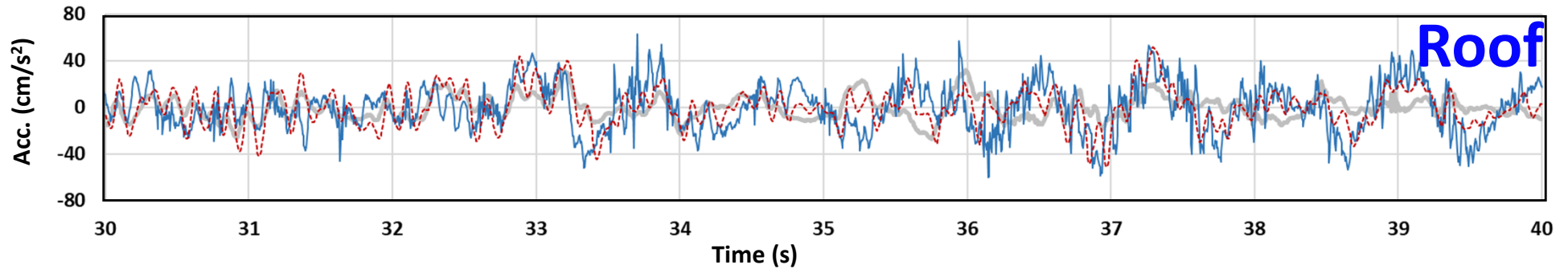


# Vertical Acc. Response



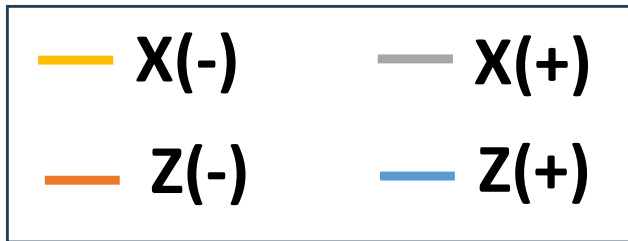
— Ground Motion    — Measured (C)    - - - PISA3D (top of column C3)

Position C3 is close to the accelerometer



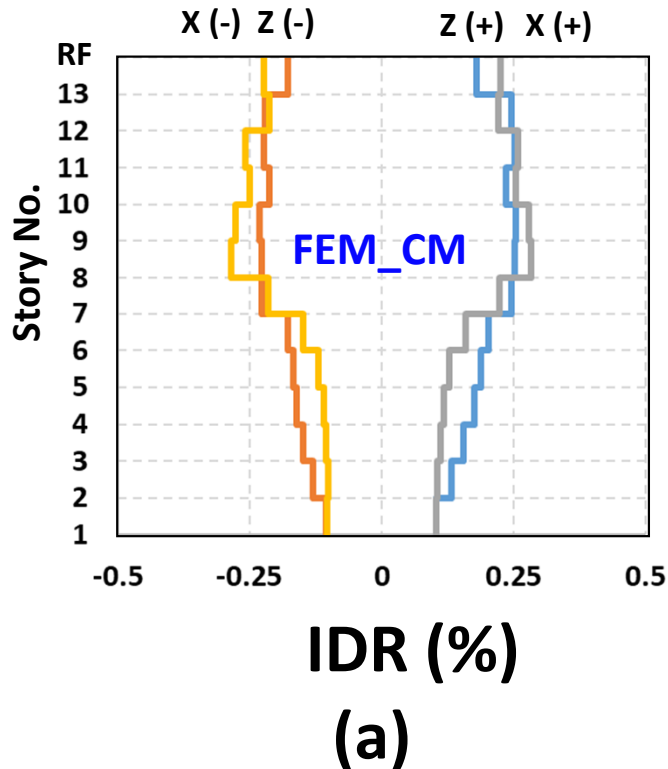
# Estimated Peak Inter-story Drift Ratios (IDRs)

Seismic Event: E20240403T00001964

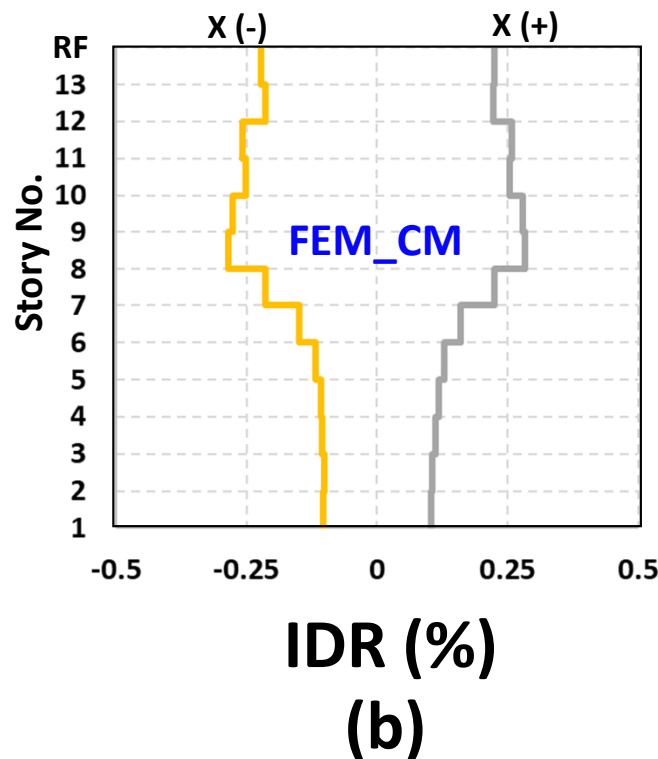


- To compare with **GBM** results, the IDRs of **FEM** are computed with at the centers of mass (**CM**) at the top and bottom of the story under consideration.

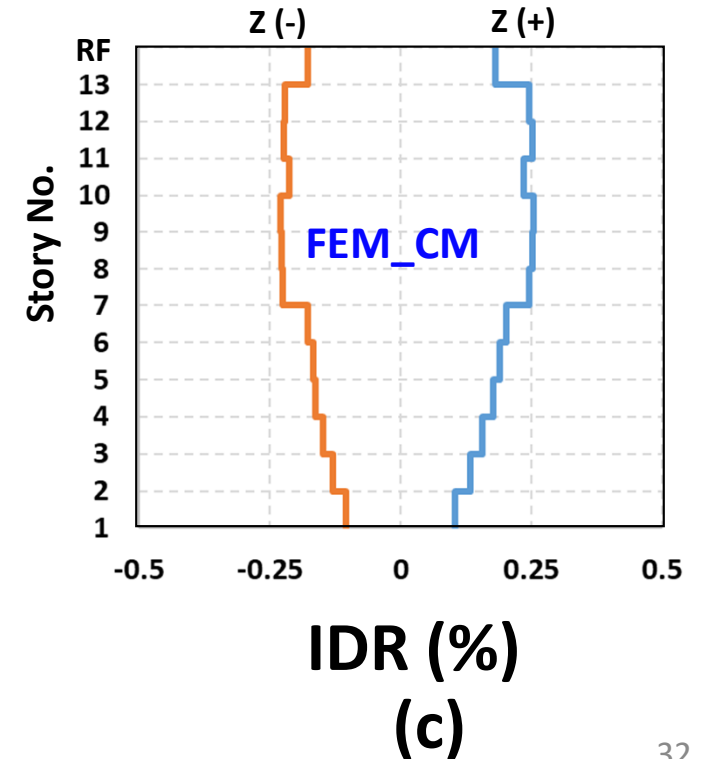
## X and Z directions



## X (LG) dir.

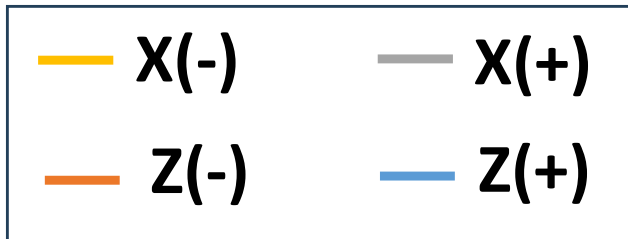
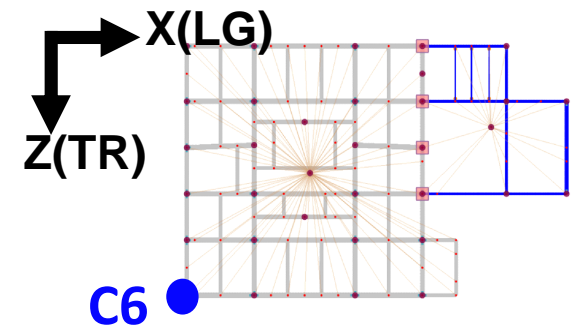


## Z (TR) dir.



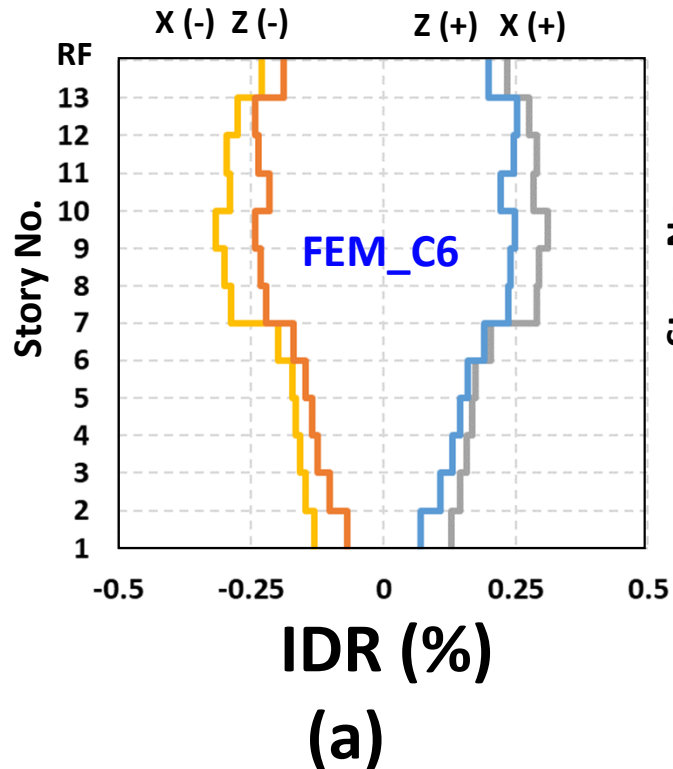
# Estimated Peak IDRs

Seismic Event: E20240403T00001964

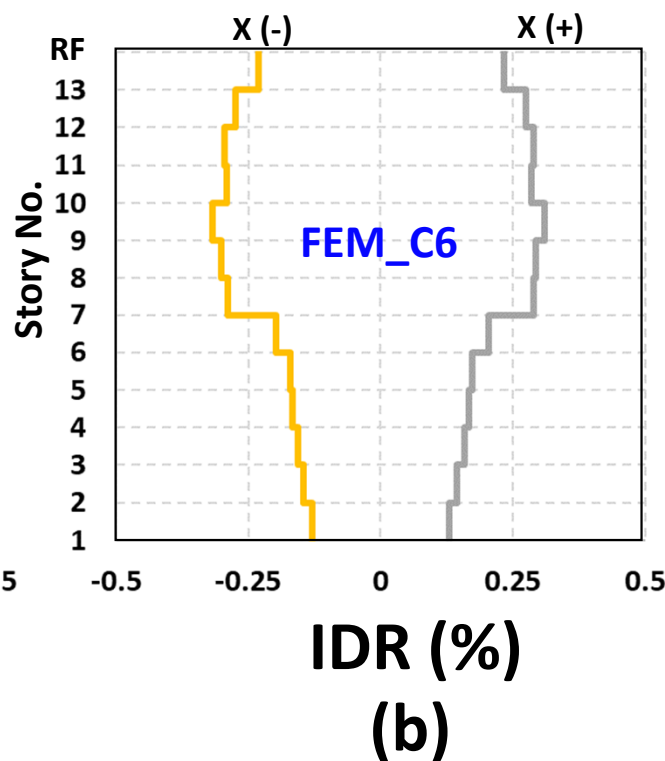


- For **comprehensive** investigation, the IDRs of **FEM** are computed with the displacements of vertically aligned points at the corner **C6**.

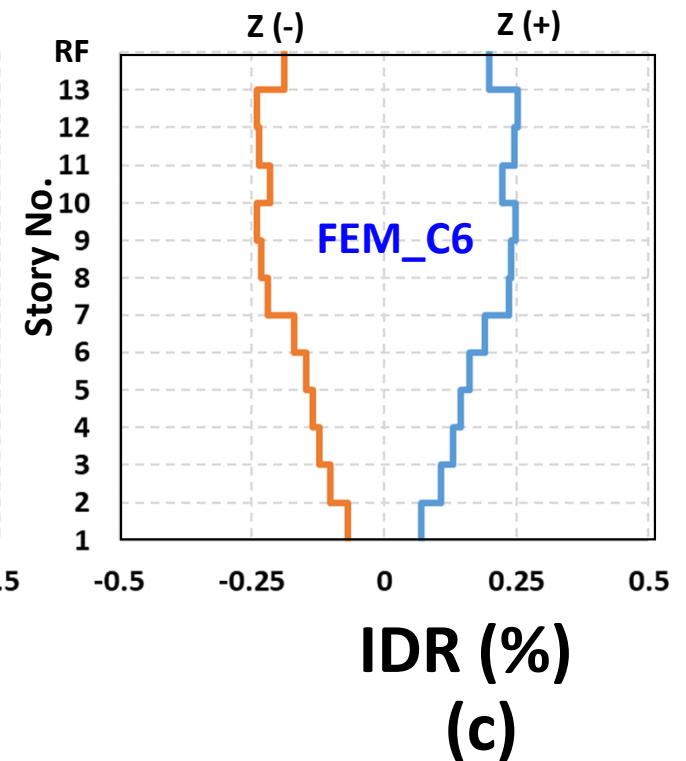
## X and Z directions



## X (LG) dir.



## Z (TR) dir.



# Estimated Absolute Maximum IDRs (GBM vs. FEM)

Seismic Event: [E20240403T00001964](#)

— GBM(+)

— GBB(-)

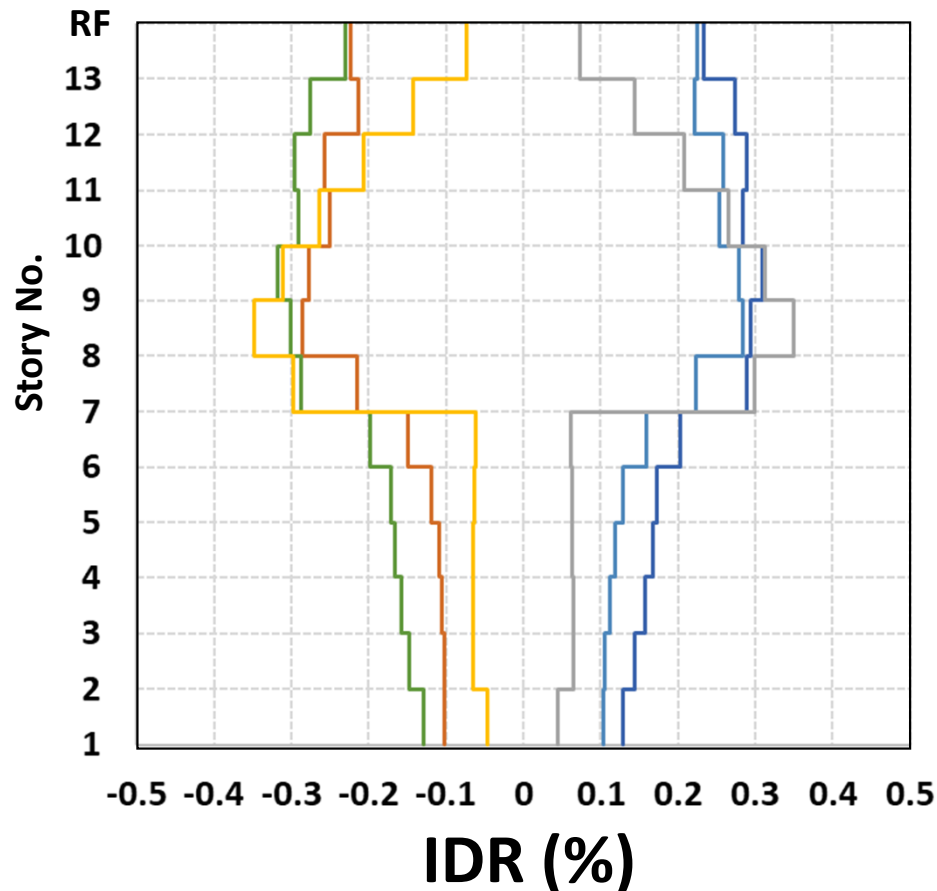
— FEM\_CM(+)

— FEM\_CM(-)

— FEM\_C6(+)

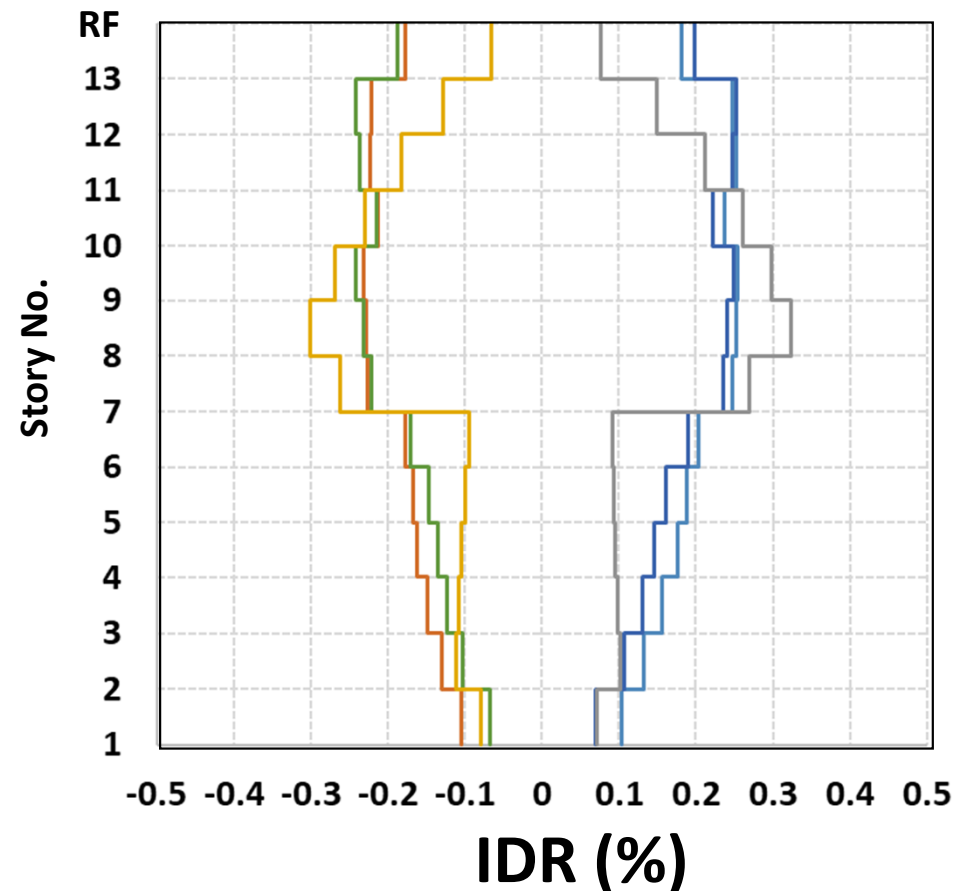
— FEM\_C6(-)

X (LG) dir.



(a)

Z (TR) dir.

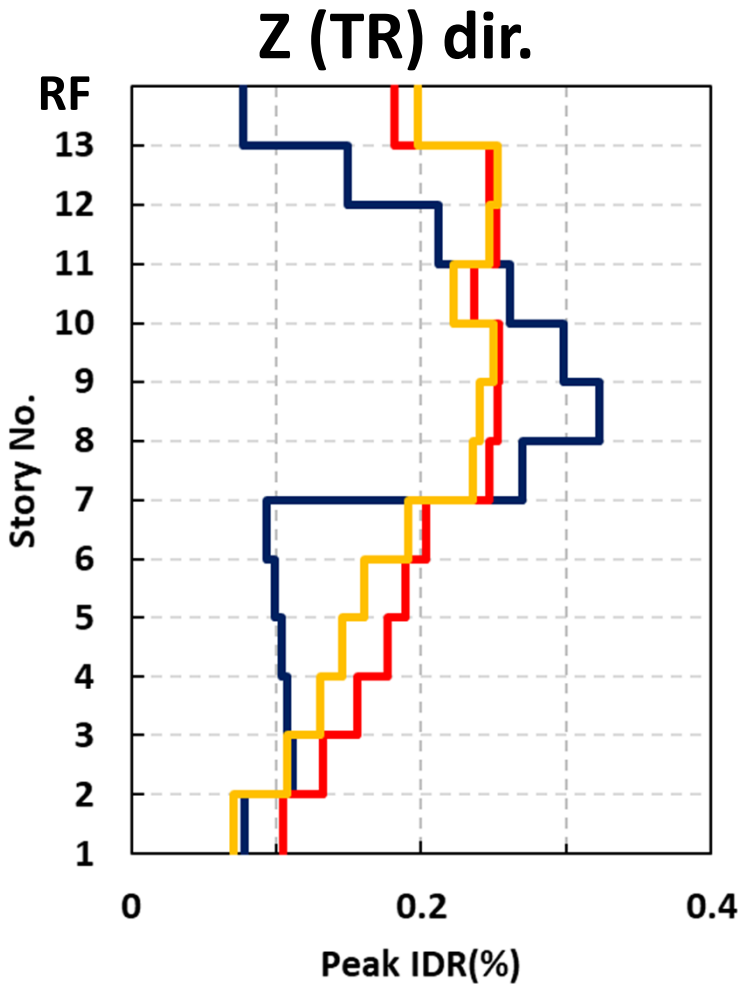
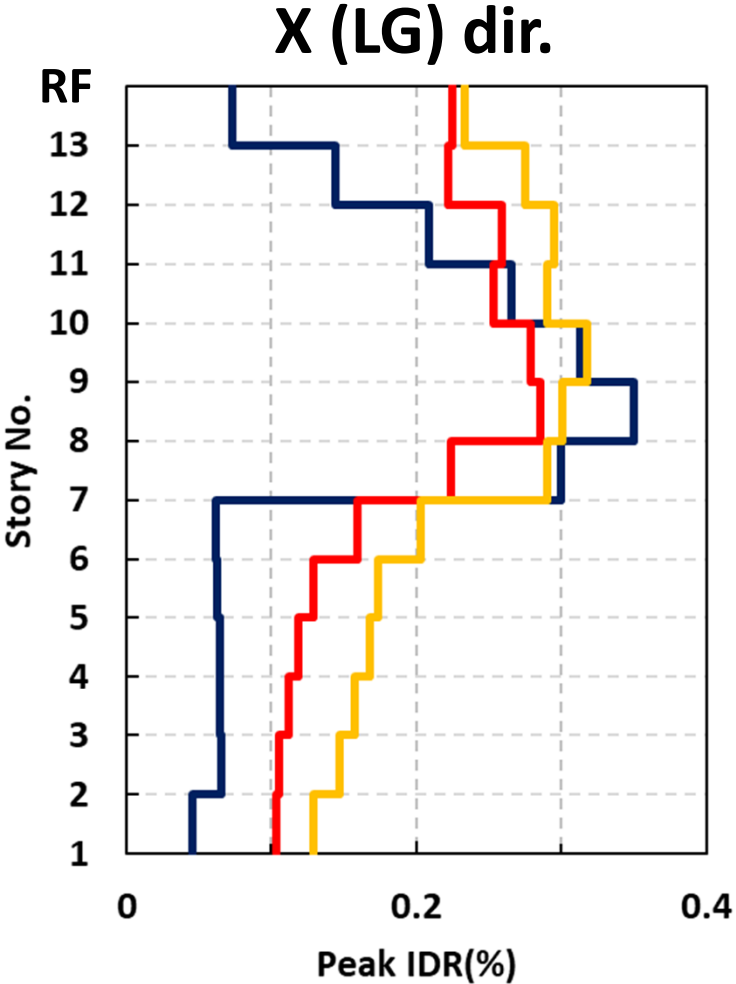


(b)

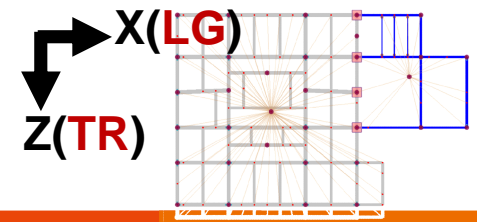


# Estimated Absolute Maximum IDRs in X Dir. (GBM vs. FEM)

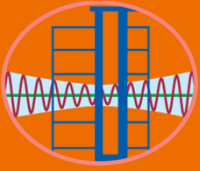
Seismic Event: E20240403T00001964



# Remarks on RHA with FEM



- The floor acc. histories of RHA and the measured data are in **good agreement**. The estimated mass distribution and the adoption of elements of **FEM** are reasonably good.
- By using **FEM**, not only the both horizontal but also the **vertical** responses can be estimated. Moreover, the effects of diaphragm **rotation** are included.
- In **LG** direction, the estimated **max. IDRs** of **FEM\_CM** and **FEM\_C6** are **0.286%** rad (at 8F) and **0.318%** (at 9F), respectively.
- In **TR** direction, the estimated **max. IDRs** of **FEM\_CM** and **FEM\_C6** are **0.254%** rad (at 9F) and **0.249%** (at 9F), respectively.
- All **IDRs** are less than **0.32%** rad. The satisfactory **seismic performance** of the building can be validated.



# Conclusions

# Conclusions (1)

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- The floor acc. histories of **response history analyses** and the **measured data** are in good agreement. Thus, **GBM** and **FEM** are reasonable good for predicting the earthquake responses is validated.
- With the estimated **absolute maximum IDRs** of GBM and FEM, the **similar trends** of varied IDRs along the height dir. can be observed.
- **GBM** enables a very fast and efficient post-earthquake response estimation with **conservatism** regarding the peak IDR.

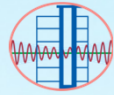
# Conclusions (2)

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- **FEM** can be used to identify the critical structural member for further inspection if needed.
- **GBM** and **FEM** can supplement each other for the post earthquake seismic assessment of buildings.
- Through RHAs using **GBM** and **FEM**, all estimated IDRs are less than **0.35%** rad. **The safety and the satisfactory seismic performance of the building can be validated.**



# Thank you.



NCRE

