EGU General Assembly 2020 Online | 4–8 May 2020

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Rotational waves in fragmented and blocky geomaterials

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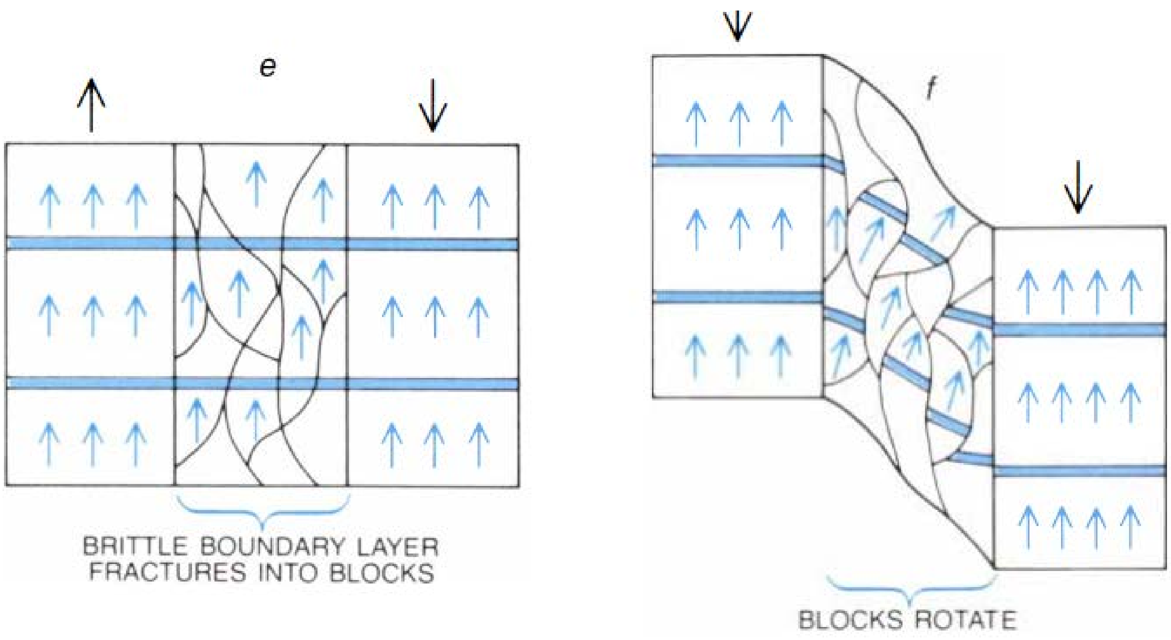
Introduction and Motivation

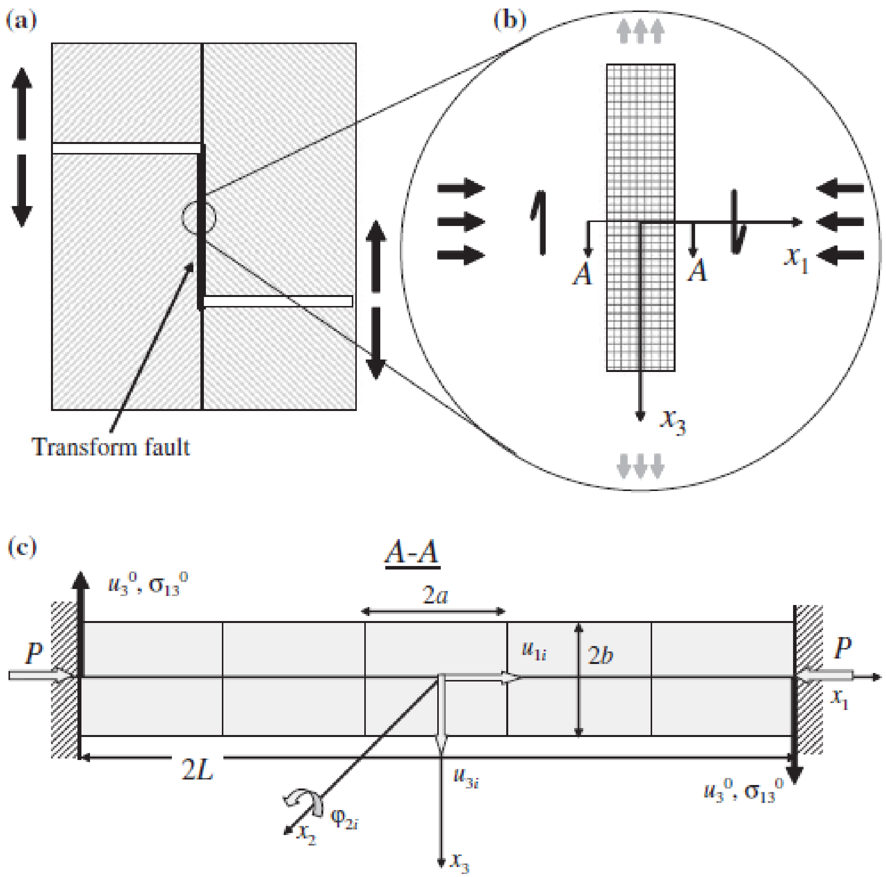
Jones et al. (1990) shows the presence of large rotations of crustal blocks in the western part of the San Andreas Fault by the paleomagnetic measurements (blue arrows in the diagram below):



(Jones et al, 1990)

Introduction and Motivation

Modelling of Deformations of Transform Fault (Pasternak et al. 2006)



(Pasternak et al. 2006)

Introduction and Motivation

- The fragmented/blocky geomaterials are convenient to model using osteomorphic blocks column as they are stable, while the blocks are not bonded together

- The osteomorphic blocks have a special shape that ensures topological interlocking, which keeps the blocks together

- The osteomorphic assembly is an engineered material with internal architecture which captures the fragmented and blocky nature of geomaterials

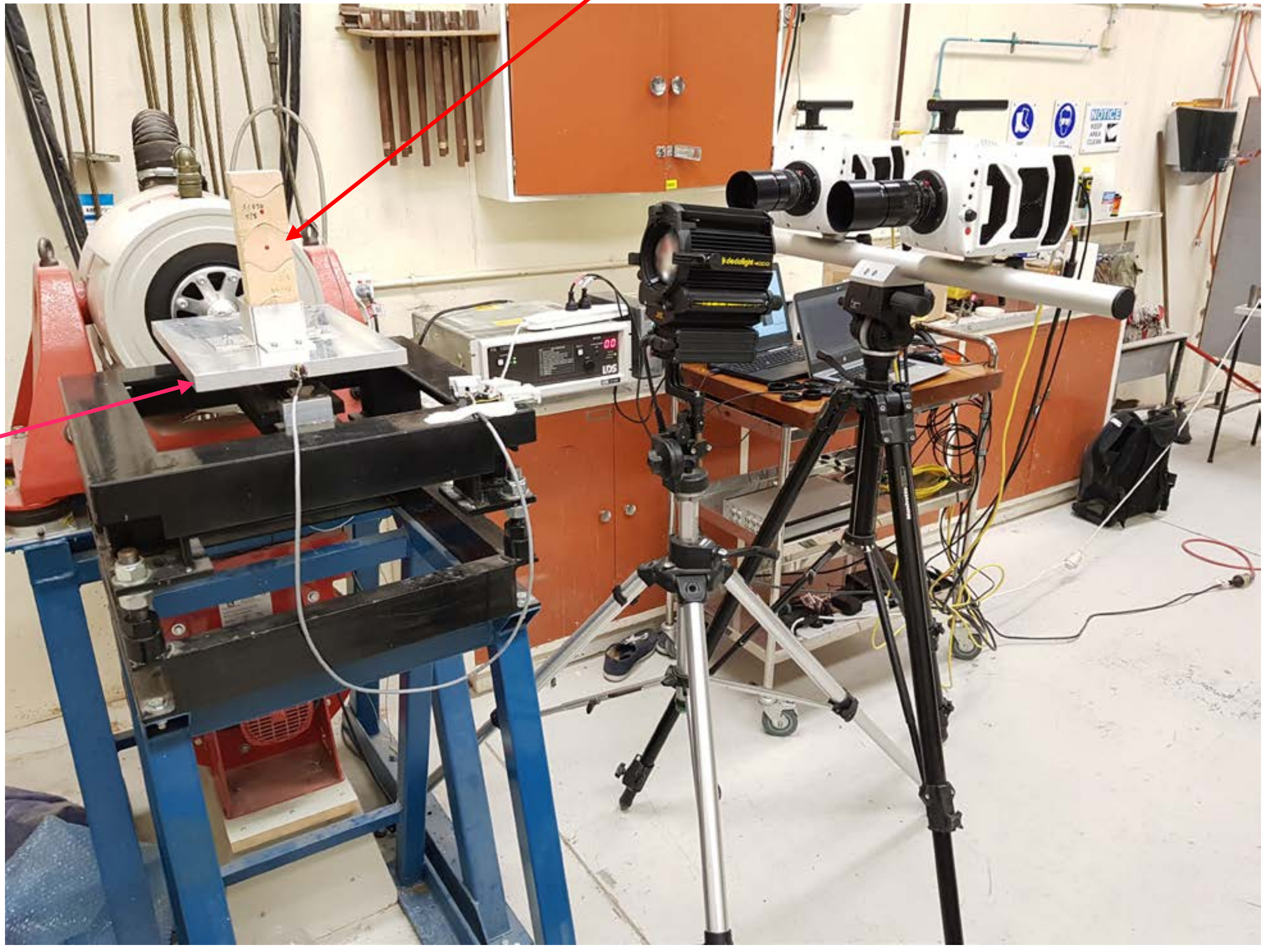
- A series of vibration tests on osteomorphic blocks columns were conducted using a shaker table to investigate the rotational wave travelling within the assembly, the associated energy and the spectrum of the block oscillations with the aid of DIC technique

(Dyskin et al. 2012a)

Experimental Set-up

Overall Experimental Set-up

Blocky column



Sharer table

Experimental Set-up

Main Components of Shaker Table System

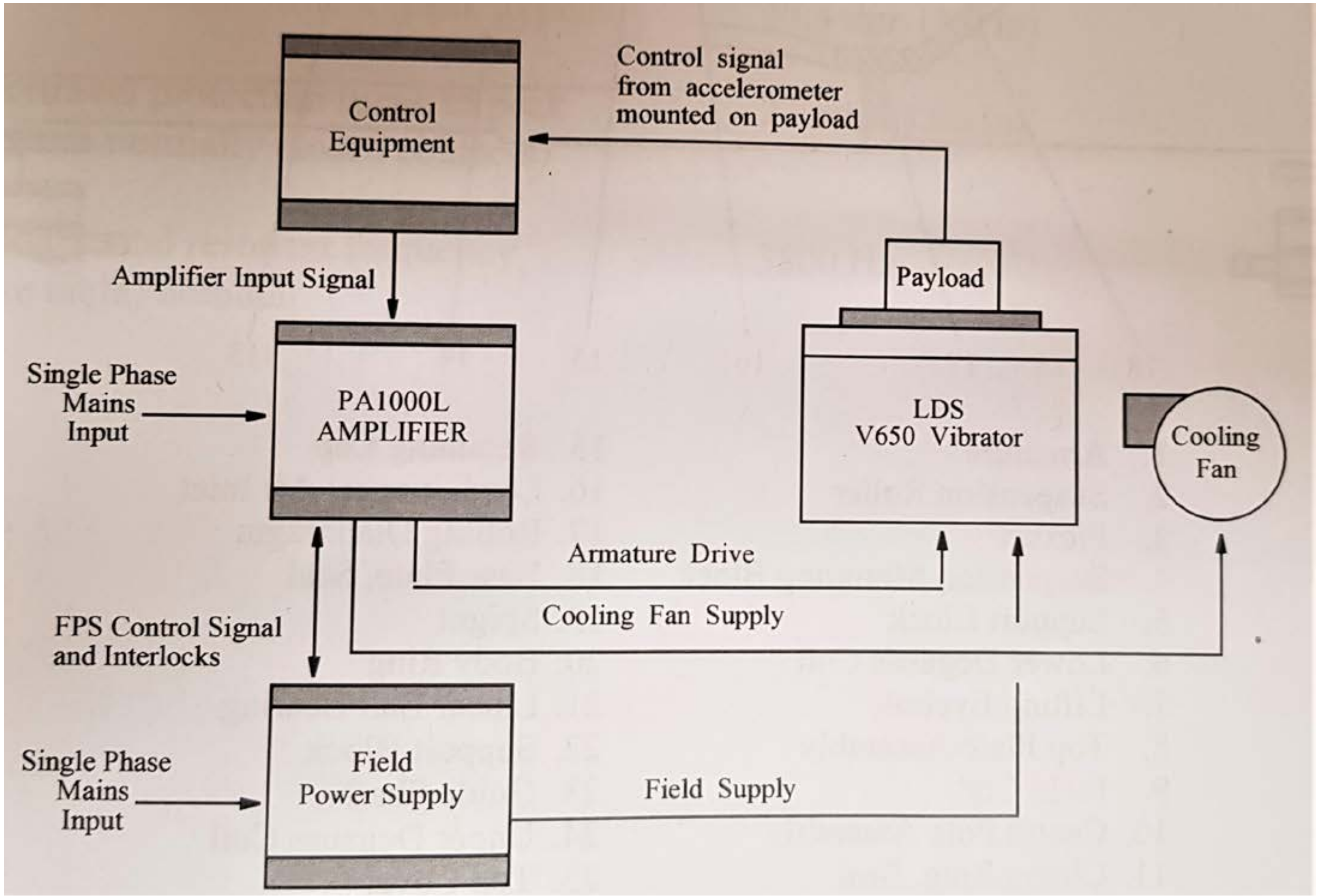
- LDS V650 Series Vibrator with Cooling Fan
- PA1000L Amplifier
- Shaker Control System
- FPS10L Field Power Supply

V650 Vibrator

Amplifier, Control System, Power Supply

Experimental Set-up

Flow Chart of the V650-FPS10L-PA1000L Shaker Table System



(From LDS V650 Vibrator User Manual)

Experimental Set-up

Key Specifications of the V650-FPS10L-PA1000L Shaker Table System

- Usable frequency range: 5 – 4000 Hz
- Maximum acceleration (sine peak): 722 m/s^2
- Maximum acceleration (random peak): 486 m/s^2
- Maximum displacement (Peak to Peak) : 25.4 mm

Experimental Set-up

Main Components of High-speed Camera System

- Two Phantom high-speed cameras with Canon lenses
- Tungsten-halogen light (provide 4.5° - 48° beam spread)
- Data acquisition system

Experimental Set-up

Key specifications of Phantom High-speed Camera (V2640 series)

- Frame per second (FPS) range: 0.005 – 500,000 Hz
- Resolution of image depends on FPS (see Table)
- Record times: 7.8 seconds at max FPS
- Operating temperature: -10 to 50 °C
- Humidity: 95% non-condensing

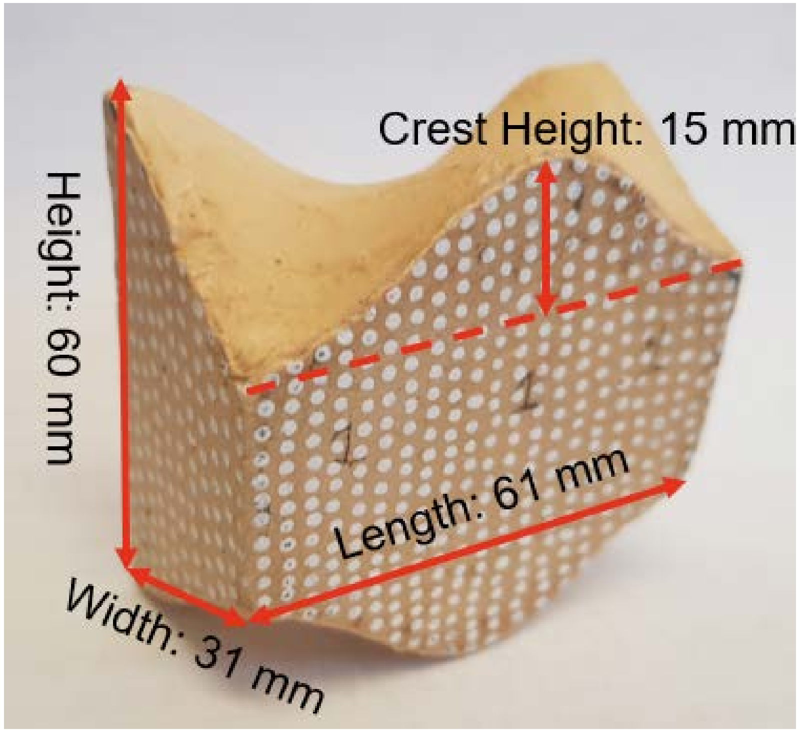
Resolution	FPS
2048 × 1952	6,600
1920 × 1080	12,500
1024 × 976	14,740
1792 × 720	19,690
640 × 480	28,760
1792 × 8	303,460

(phantomhighspeed.com/products/cameras/ultrahighspeed/v2640)

Experimental Set-up

Sample

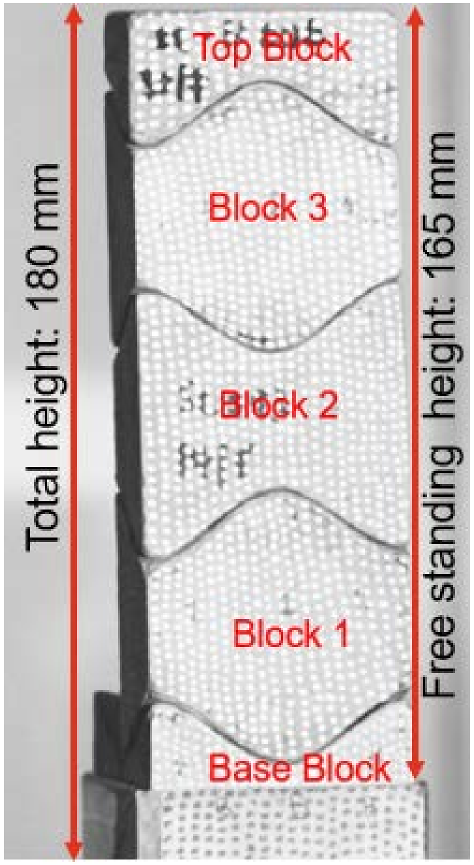
- Material of Osteomorphic blocks: gypsum
- Single Osteomorphic block weight: 167 g
- Dimensions of single Osteomorphic block:



Experimental Set-up

Blocky Column

- The column consists of 3 full blocks and 2 half blocks
- Top and base blocks are half osteomorphic blocks
- Blocks 1, 2 and 3 are full osteomorphic blocks
- Base block is tightly constraint by four L-shape plates bolted to the shaking table, i.e. base block is only allowed to move horizontally
- Blocks 1, 2, 3 and top block are stacked vertically above the base block without any bonding material in between
- Column dimension: 31 mm × 61 mm × 180 mm (width × length × height)
- Column weight: 668 g



Experimental Set-up

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Setting of shaker table in this experiment

- Acceleration range: 1 - 7 m/s^2
- Frequency range: 5 - 90 Hz
- Experiment schedule:
  - 1st set of tests (13 tests): varying frequency with constant acceleration 2.5 m/s^2
  - 2nd set of tests (7 tests): varying acceleration with constant frequency at 5 Hz
  - 3rd set of tests (7 tests): add additional block and repeat 2nd set
  - Each test: shaking at prescribed constant frequency and acceleration for 10 seconds

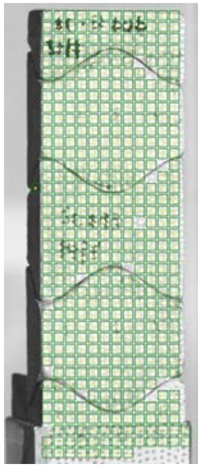
Experimental Set-up

Setting of high-speed camera in this experiment

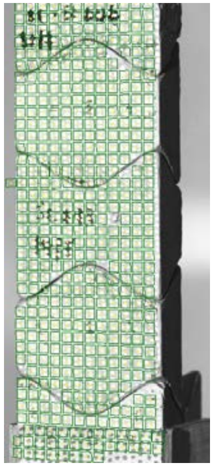
- Frame per second (FPS): 500 Hz
- Recording time: 11 seconds (1 second pre-trigger and 10 seconds post-trigger)
- Resolution of image: 384×800 pixels (Width × Height)

Setting of DIC software (Istra4D) in this experiment

- Key parameters of fast correlation mode
  - ➢ Facet size: 15 pixels
  - ➢ Grid spacing: 17 pixels
- Mask is applied to correlate area of interest



Camera 1

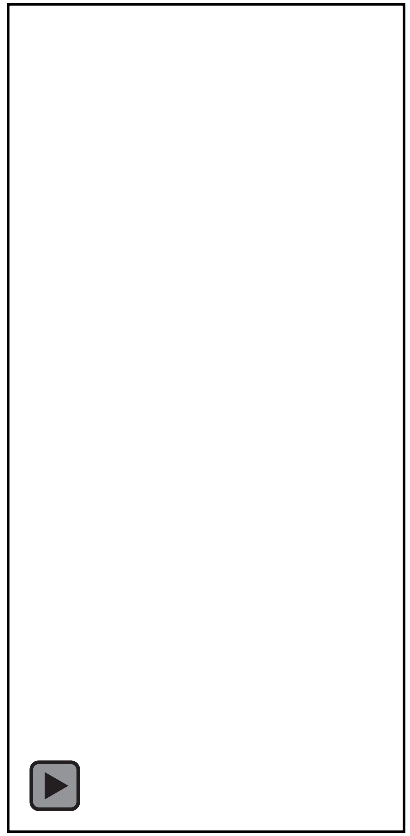


Camera 2

Results and Discussion-
5 blocks column shaking at 5 Hz and 2.5 m/s^2

1000 to 1500 steps: 2 to 3 seconds (Videos played at 10 FPS)

(Left Camera View)



(Colour arrows show the scaled total displacement field)

Results and Discussion-
5 blocks column shaking at 5 Hz and 2.5 m/s^2

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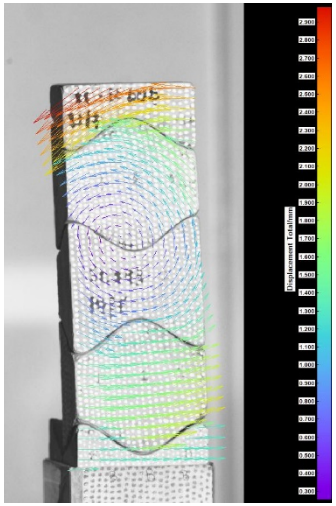
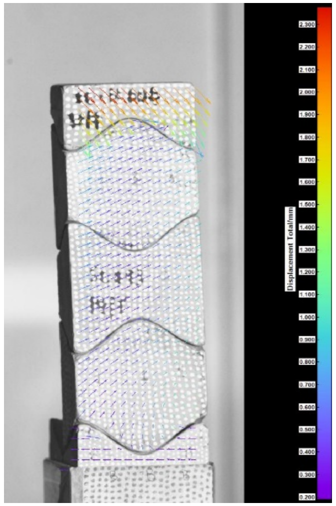
10 Snap Shots of the Scaled Total Displacement Field

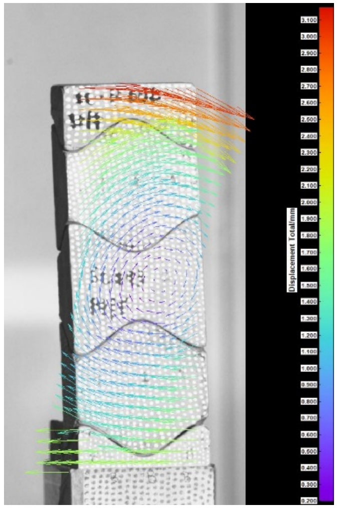
Step 1030, 2.06 sec



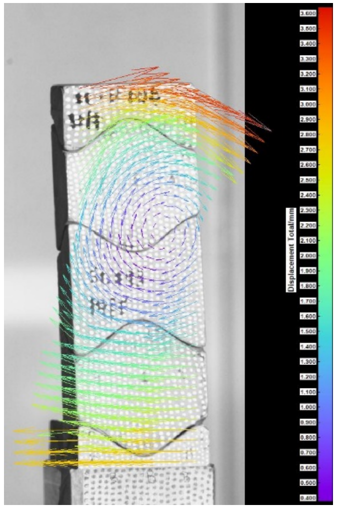
Step 1040, 2.08 sec



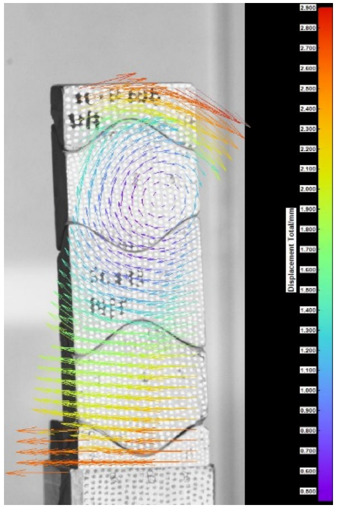
Step 1050, 2.10 sec



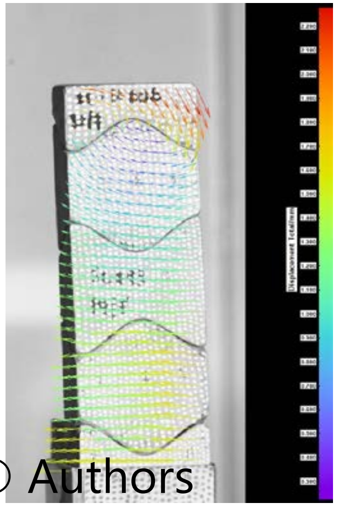
Step 1060, 2.12 sec



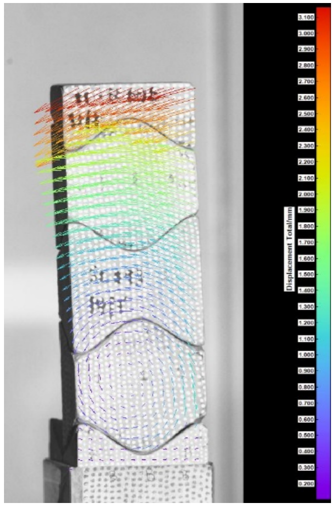
Step 1070, 2.14 sec



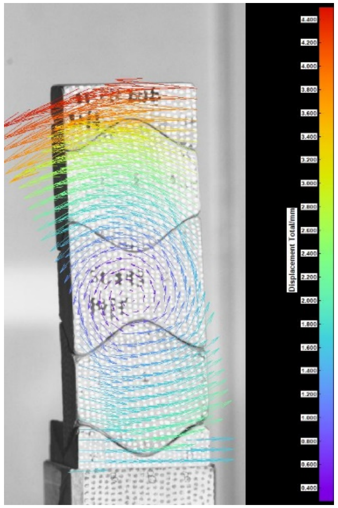
Step 1080, 2.16 sec



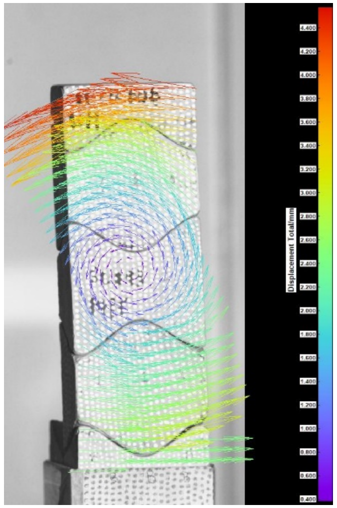
Step 1090, 2.18 sec



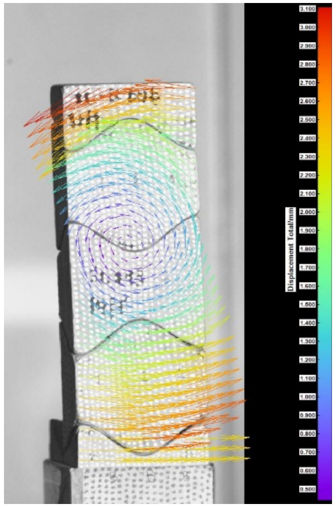
Step 1100, 2.20 sec



Step 1110, 2.22 sec

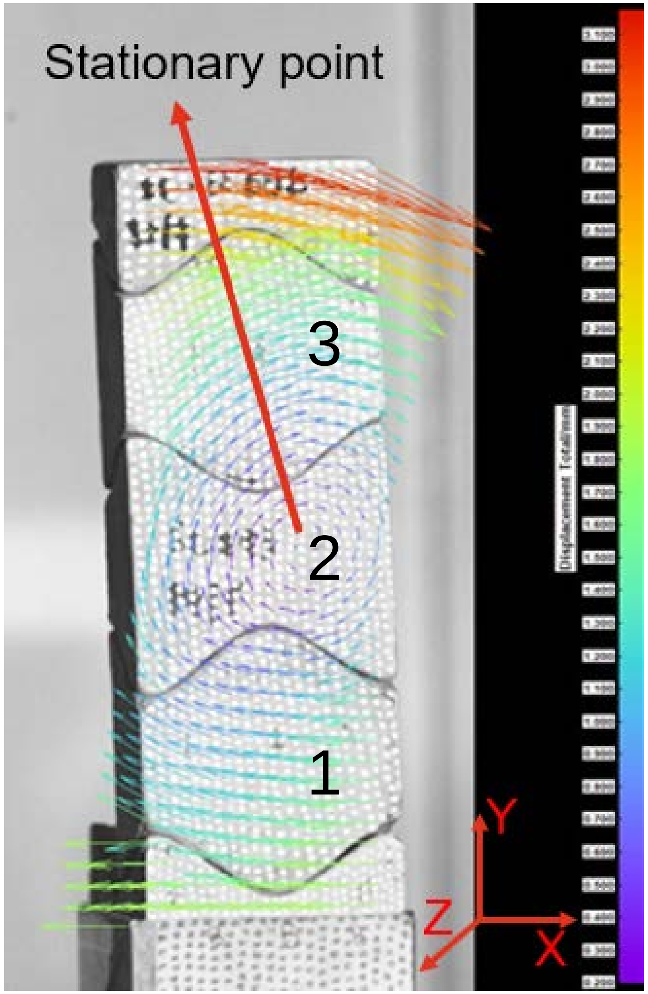


Step 1120, 2.24 sec



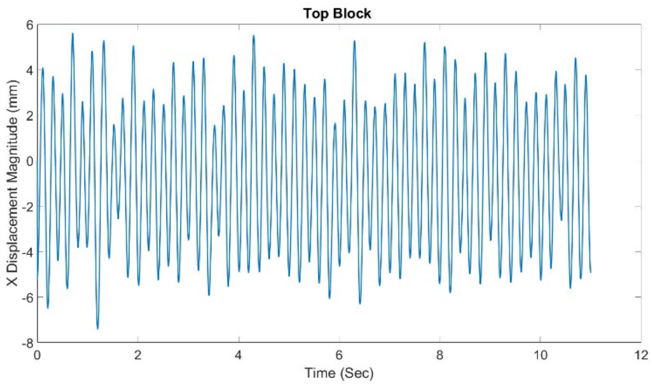
Results and Discussion-
5 blocks column shaking at 5 Hz and 2.5 m/s^2

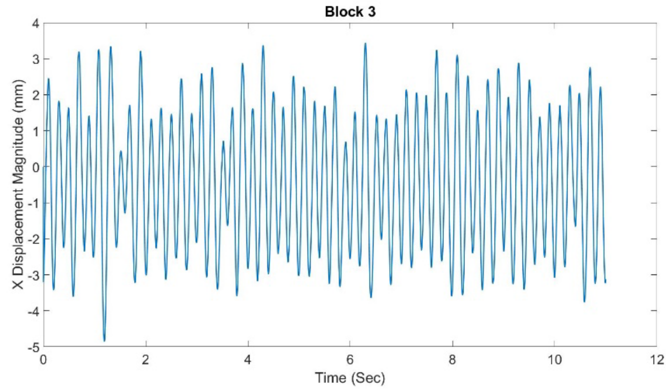
- Blocks 1, 2, 3 and the top block are observed to rock, while the base block only moves horizontally (in X direction) together with the shaking table
- 3D displacement field of the column is recovered with the aid of DIC technique
- A stationary point (centre of the rotational wave) can be seen in the column as the column was shaken at constant acceleration and frequency
- The stationary point initiates from block 1 (one block above the base block) and propagates to the top block
- The stationary point is in line with the results of the chains of bilinear oscillators reported by Dyskin et al. (2014)

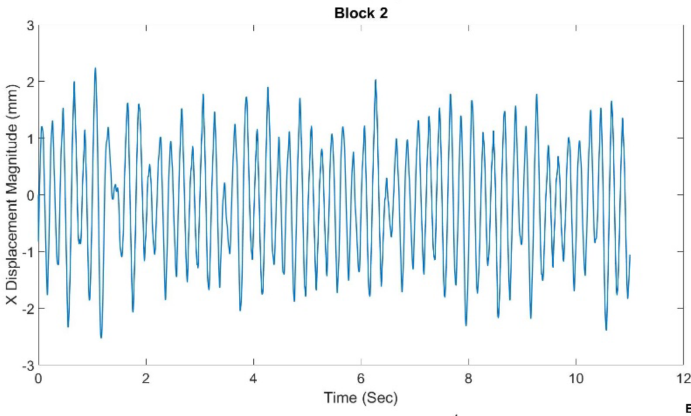


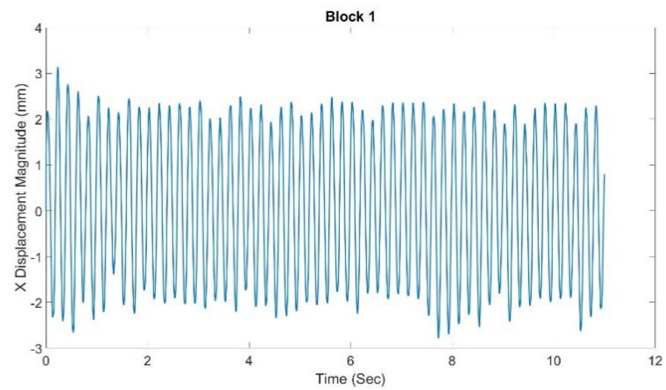
Results and Discussion-
5 blocks column shaking at 5 Hz and 2.5 m/s^2

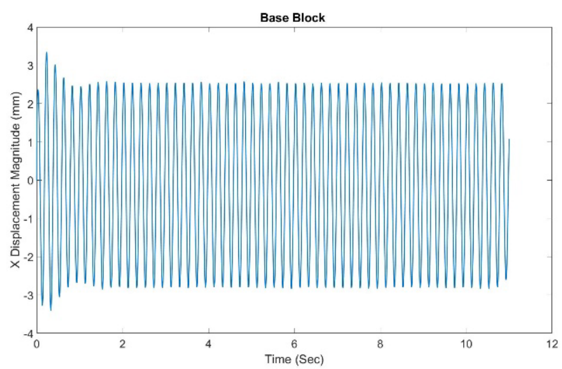
X displacement (Time Domain)

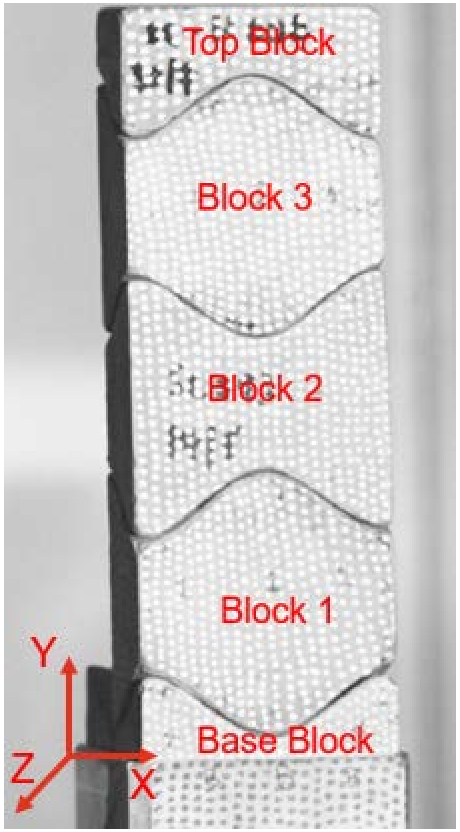








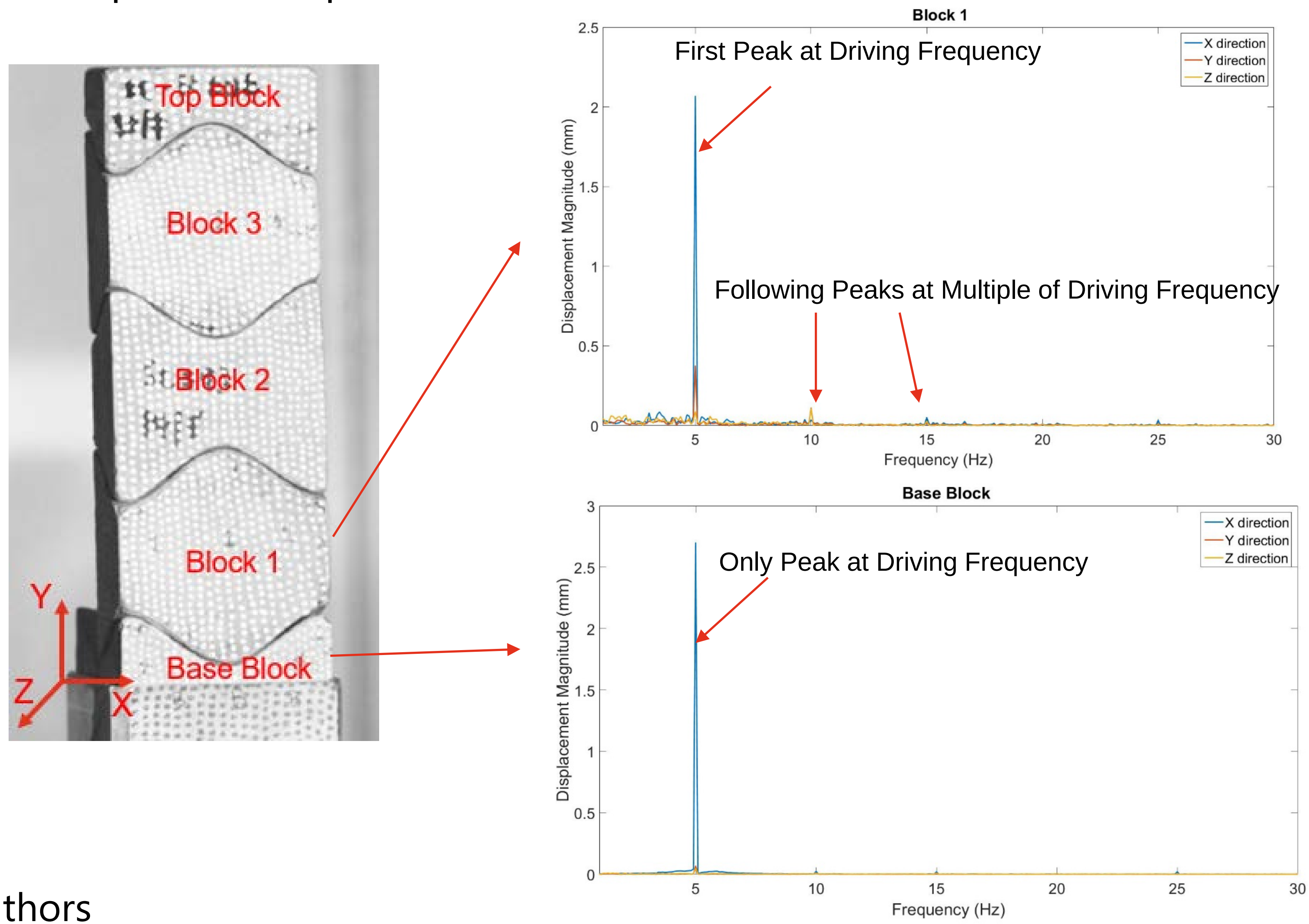




- Displacement Amplitude at Base: 2.67 mm
- Computed Input Displacement Amplitude : 2.53 mm
- Relative Error: 5.3%

Results and Discussion-
5 blocks column shaking at 5 Hz and 2.5 m/s²

Spectra of displacement field



Results and Discussion-
5 blocks column shaking at 5 Hz and 2.5 m/s^2

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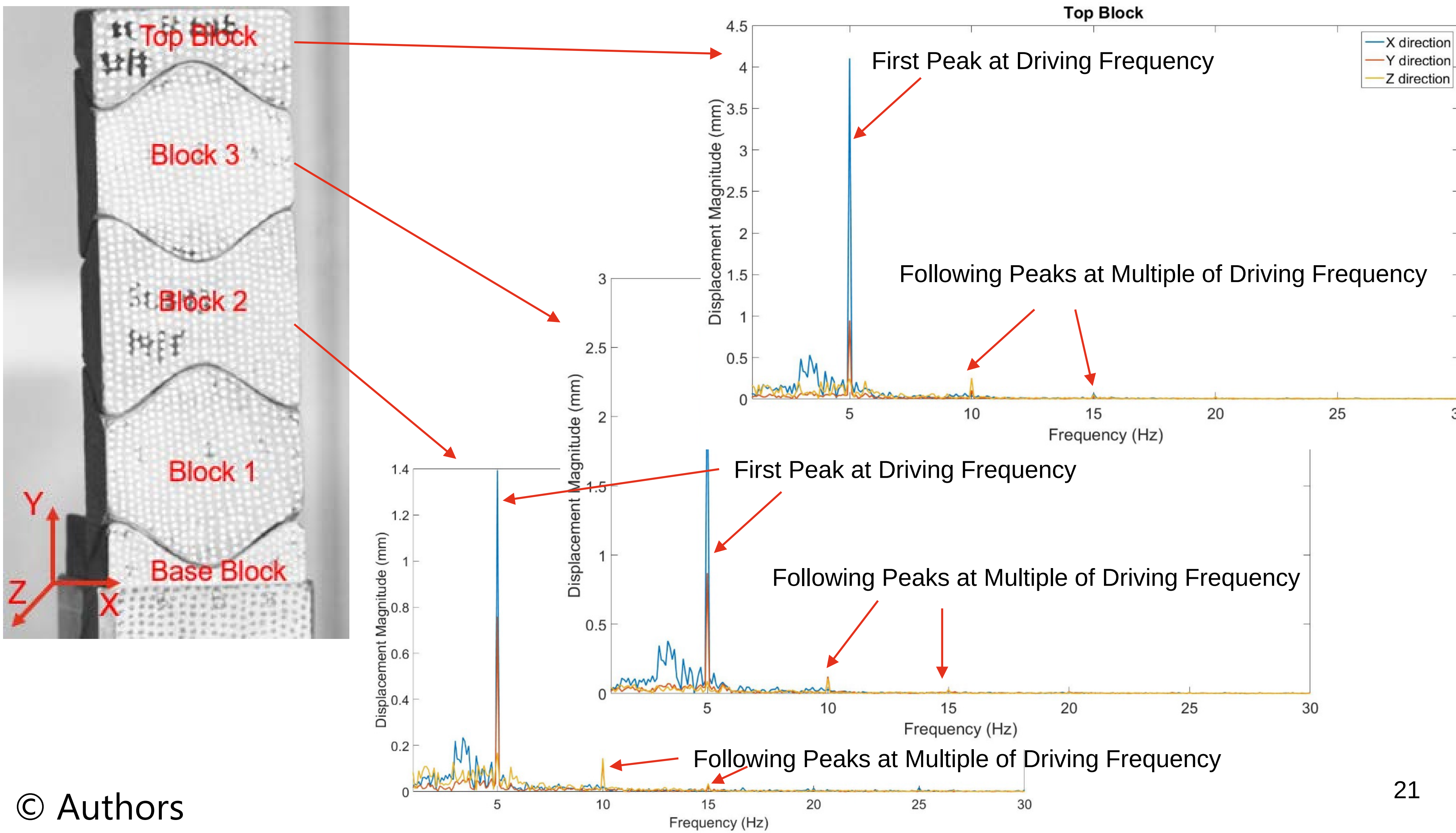
Displacement field (Frequency Domain)



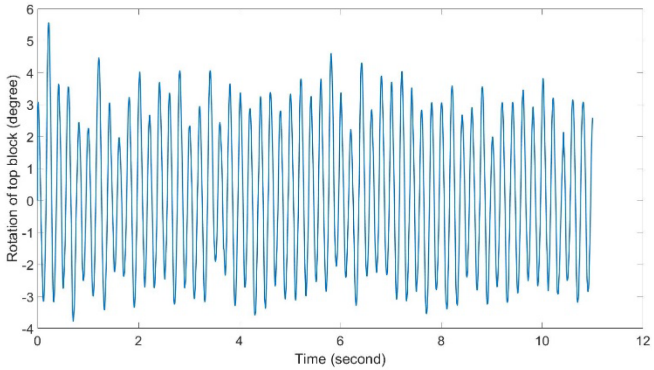
Results and Discussion-
5 blocks column shaking at 5 Hz and 2.5 m/s^2

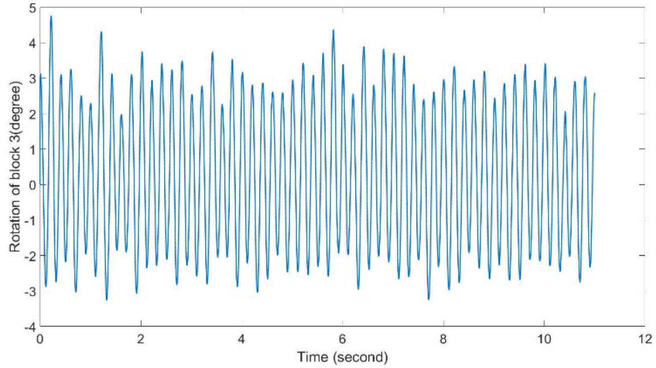
Displacement field (Frequency Domain)

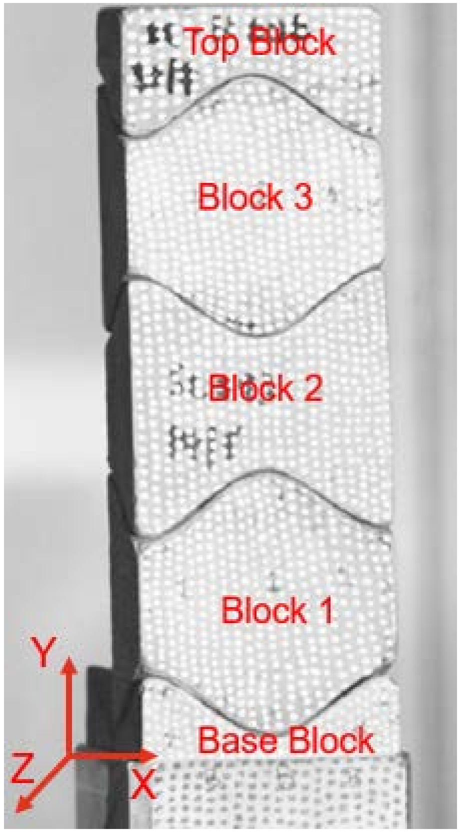
- The frequency spectra of the displacements show multiple peaks
- The first clear peak is at the driving frequency 5 Hz
- The following peaks are at the multiple of the driving frequency at 10 Hz, 15 Hz
- There are some low frequency (below driving frequency 5 Hz) vibrations observed for blocks above the base block
- The above spectral characteristic is in line with the results of the chains of bilinear oscillators reported by Dyskin et al. (2012b, 2014)

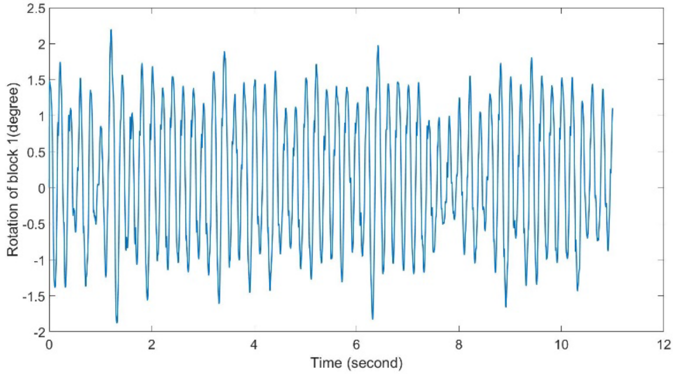
Results and Discussion-
5 blocks column shaking at 5 Hz and 2.5 m/s^2

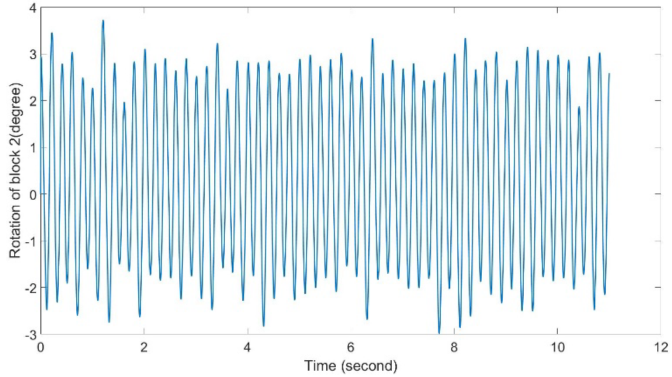
Rotation in XY plane (Time Domain)

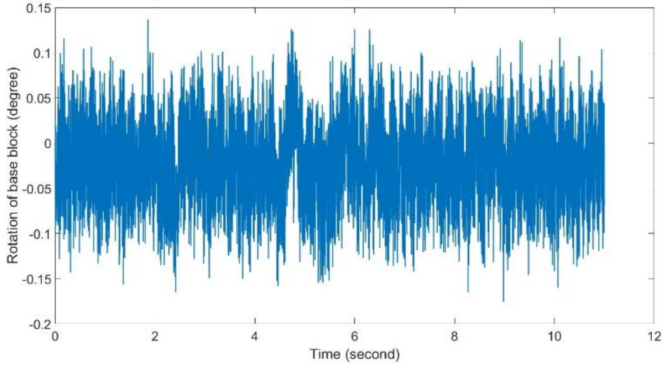






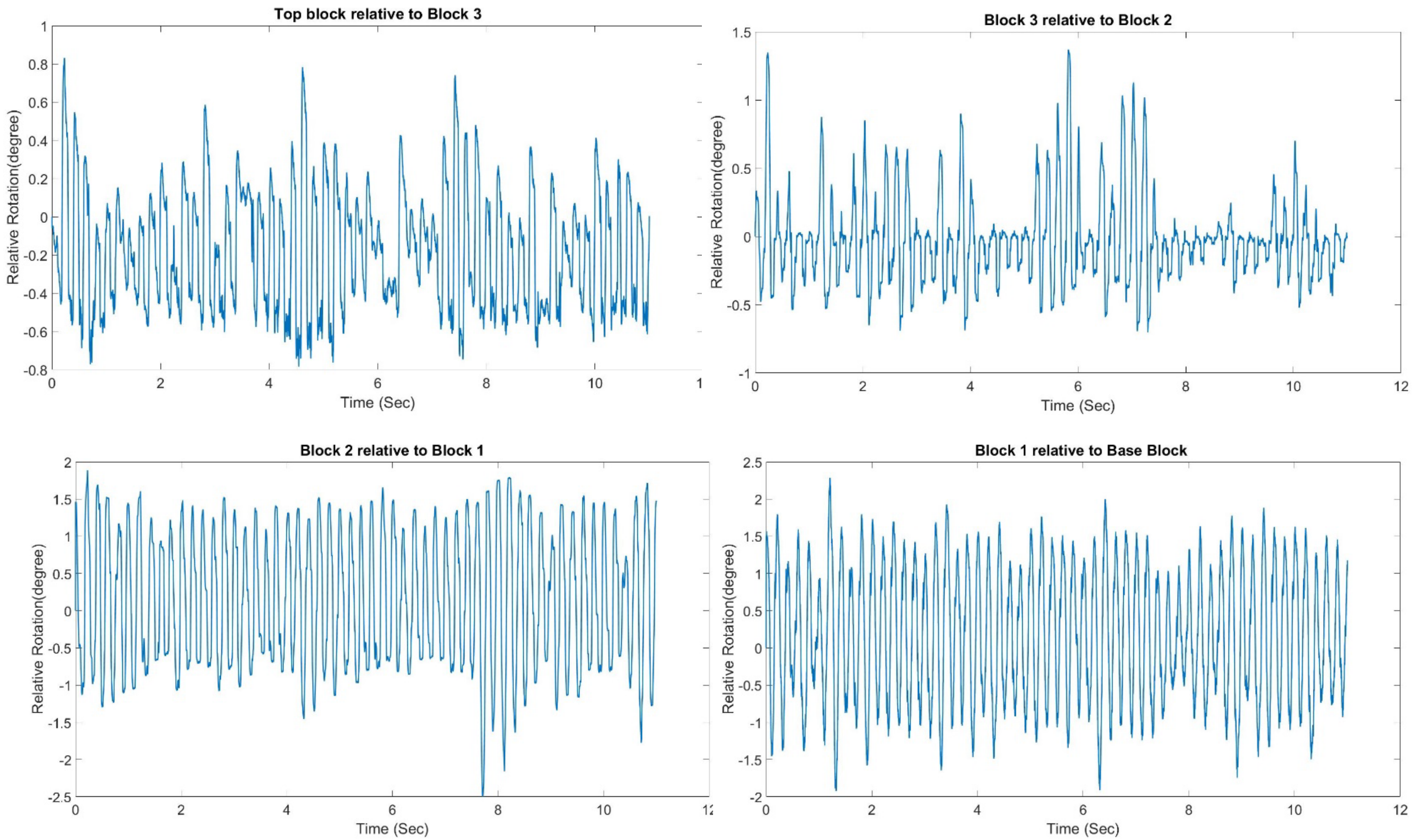


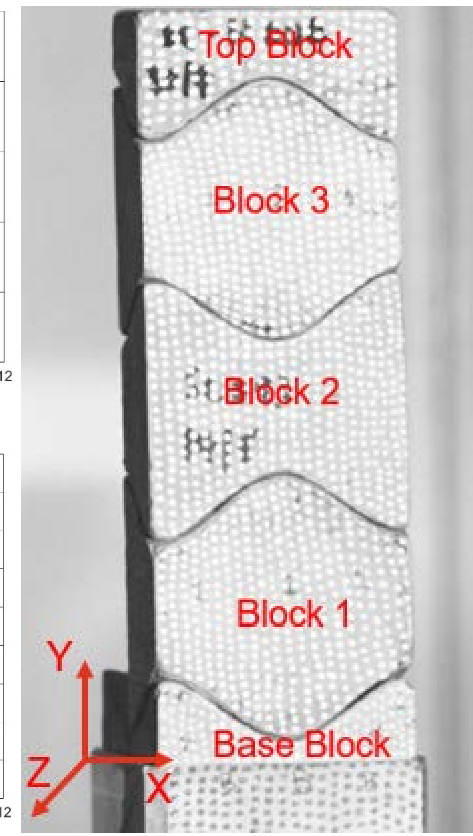




Results and Discussion-
5 blocks column shaking at 5 Hz and 2.5 m/s^2

Relative Rotation in XY plane (Time Domain)





Results and Discussion-
5 blocks column shaking at 5 Hz and 2.5 m/s^2

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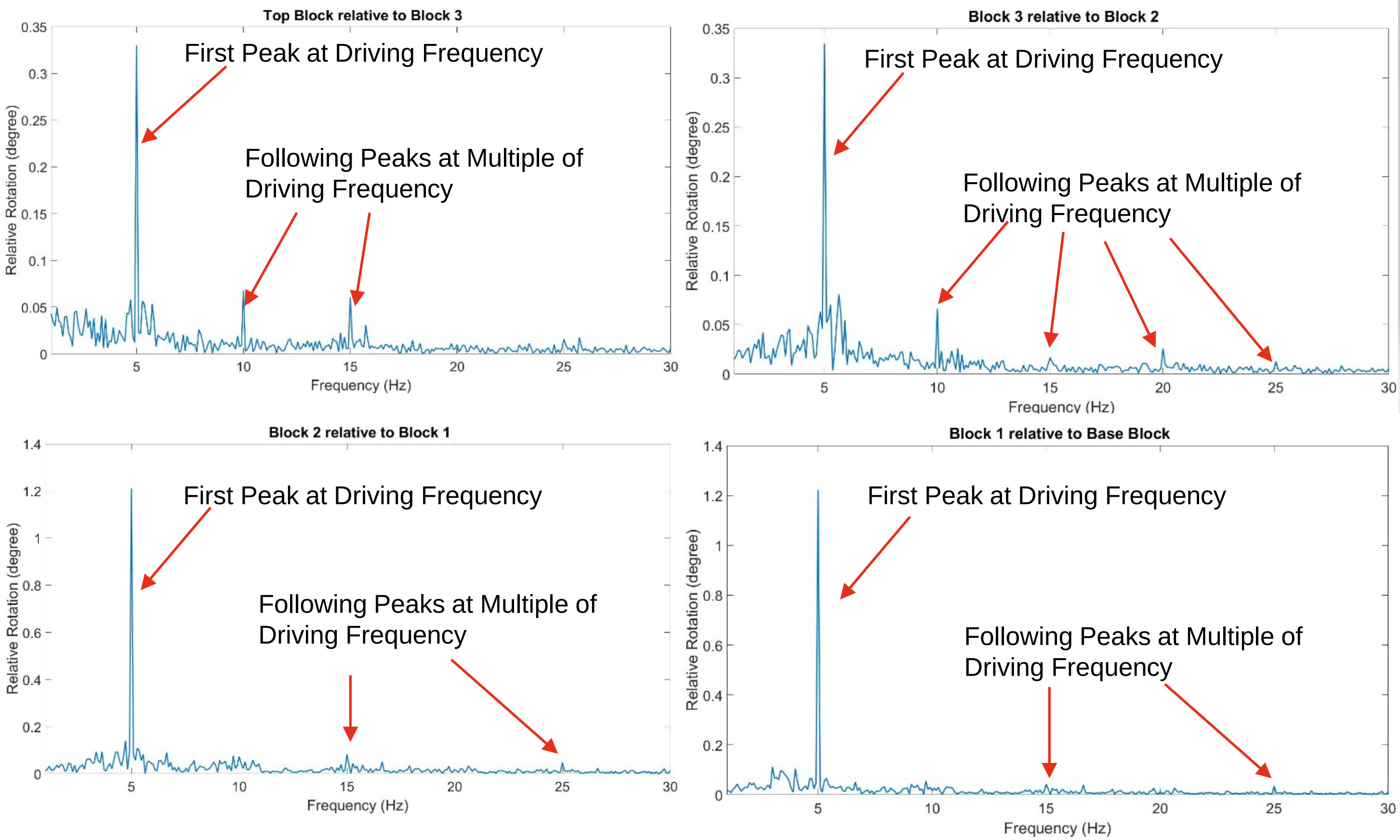
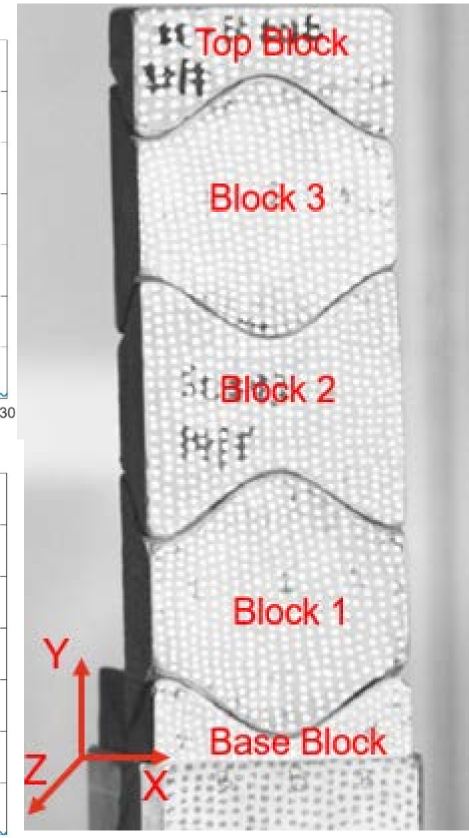
Spectra of Relative Rotation in XY plane





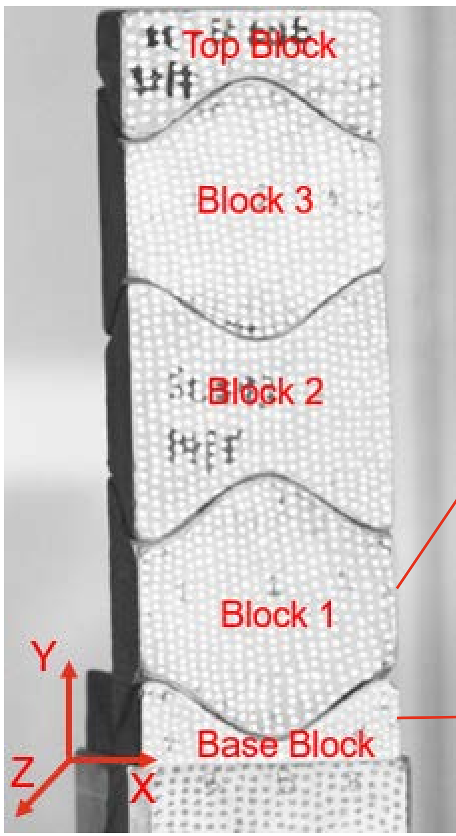
Results and Discussion-
5 blocks column shaking at 5 Hz and 2.5 m/s^2

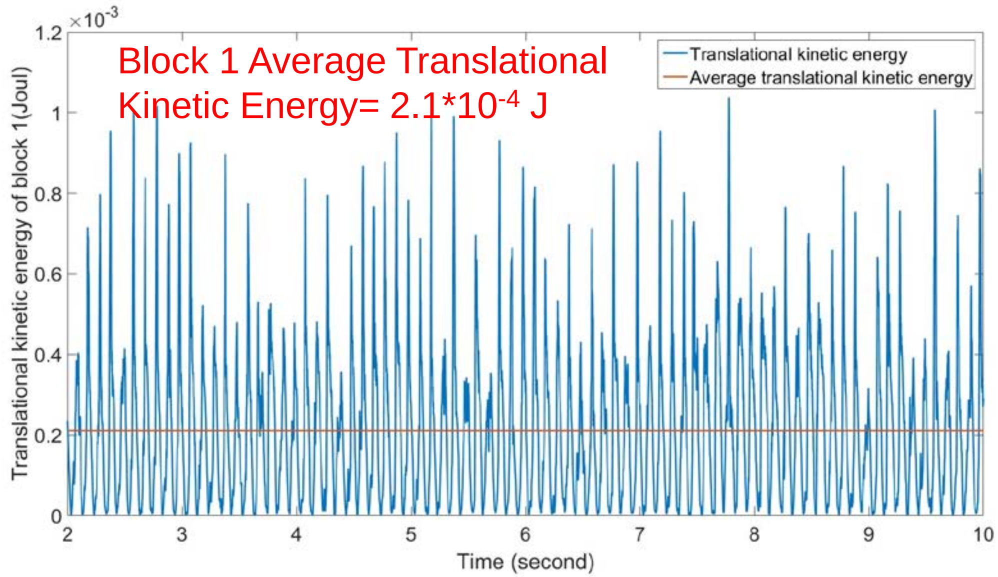
Relative rotation (Frequency Domain)

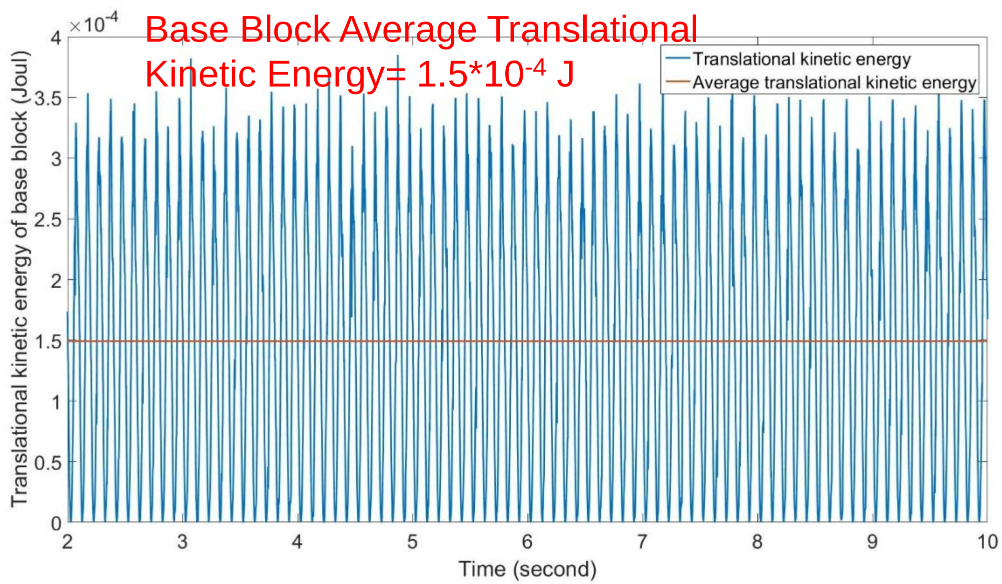
- The frequency spectra of the relative rotations show multiple peaks
- The first clear peak is at the driving frequency 5 Hz
- The following peaks are at the multiple of the driving frequency at 10 Hz, 15 Hz, 20 Hz and 25 Hz
- The above spectral characteristic is in line with the results of the chains of bilinear oscillators reported by Dyskin et al. (2012b, 2014)

Results and Discussion-
5 blocks column shaking at 5 Hz and 2.5 m/s^2

Translational Kinetic Energy

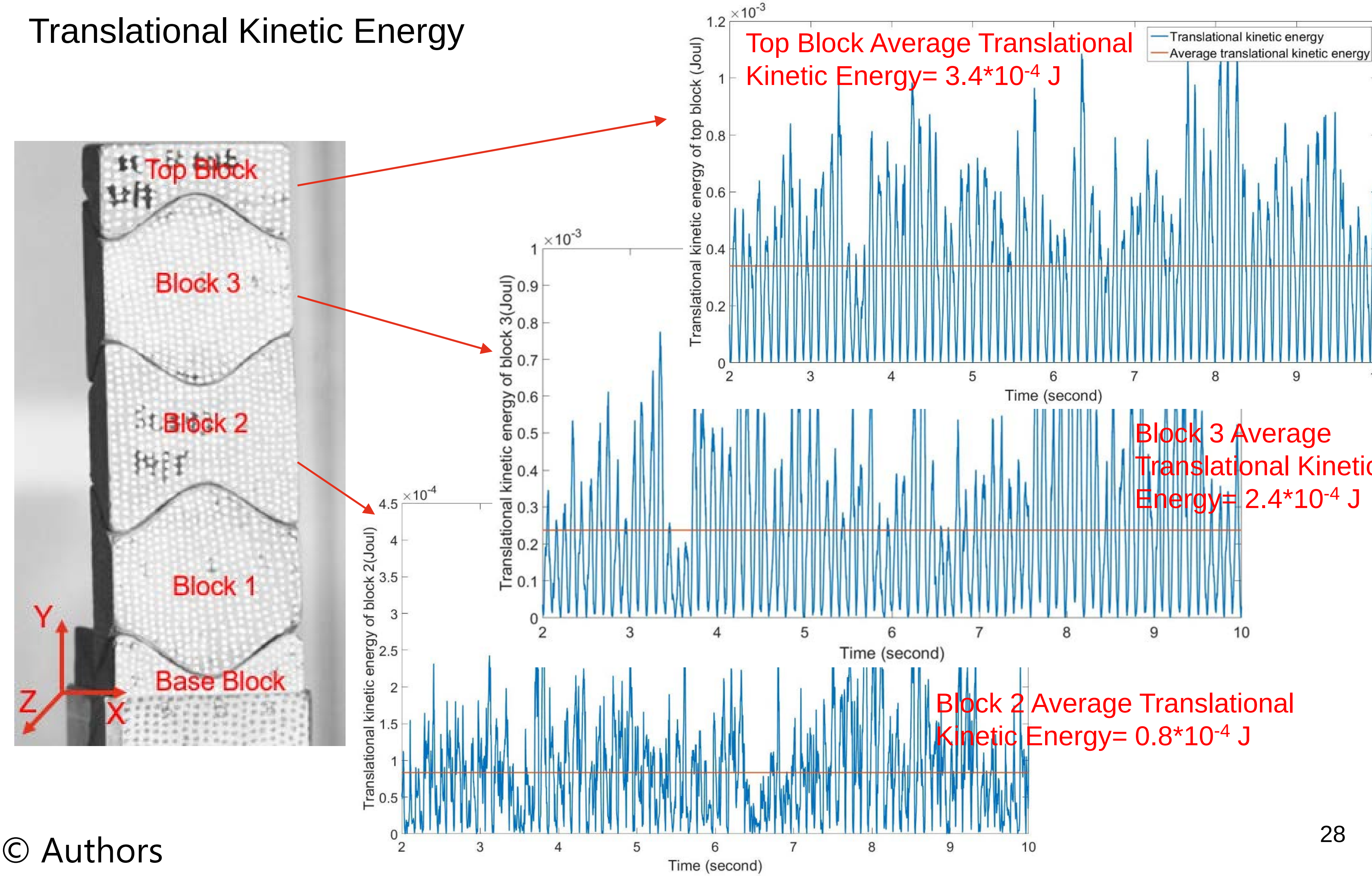






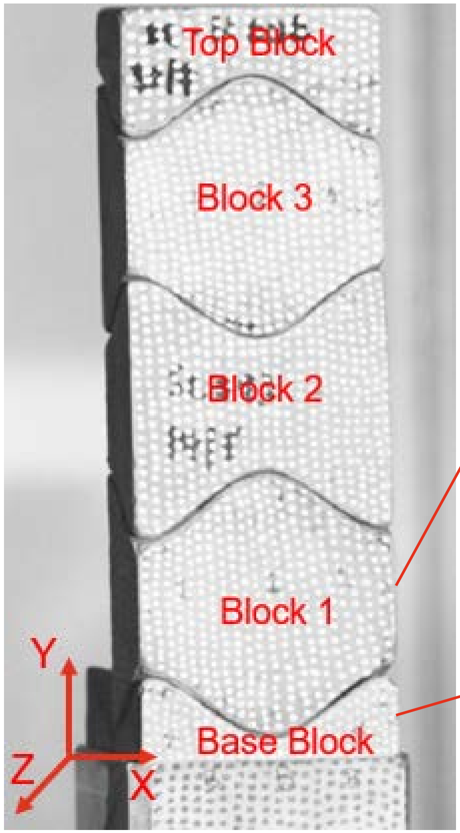
Results and Discussion-
5 blocks column shaking at 5 Hz and 2.5 m/s²

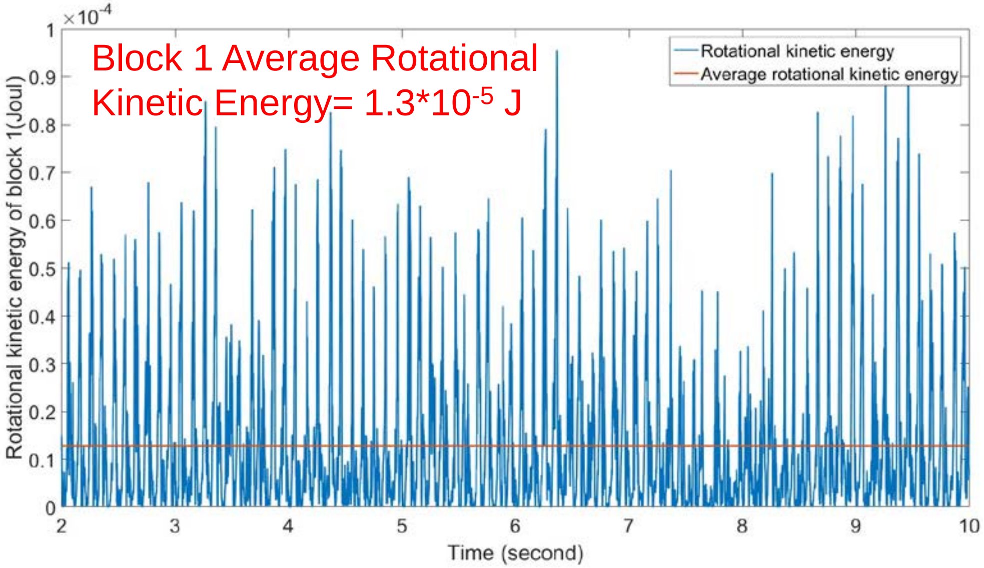
Translational Kinetic Energy

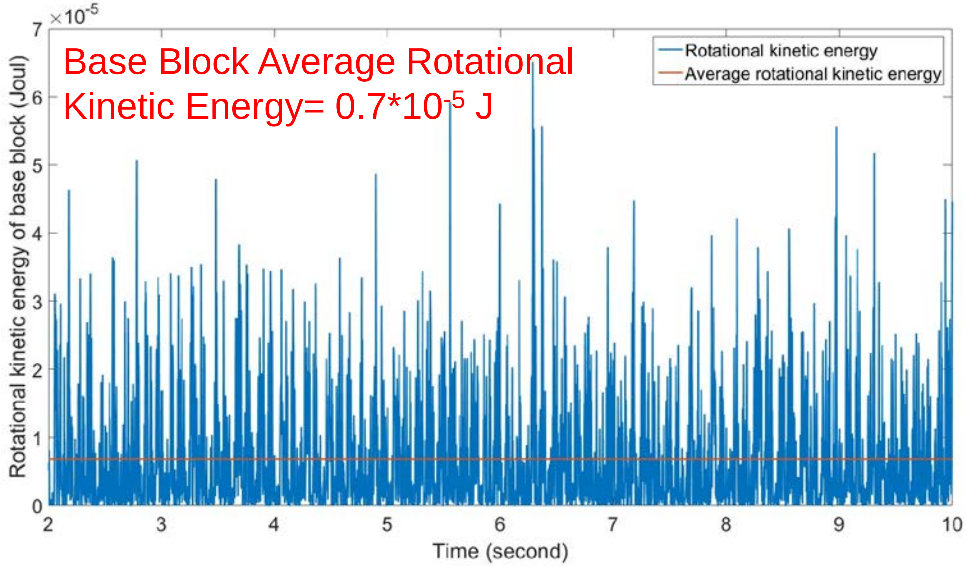


Results and Discussion-
5 blocks column shaking at 5 Hz and 2.5 m/s²

Rotational Kinetic Energy

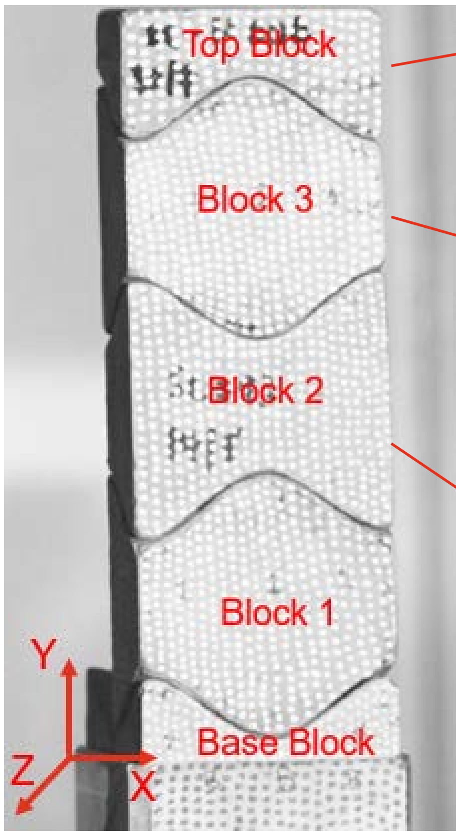


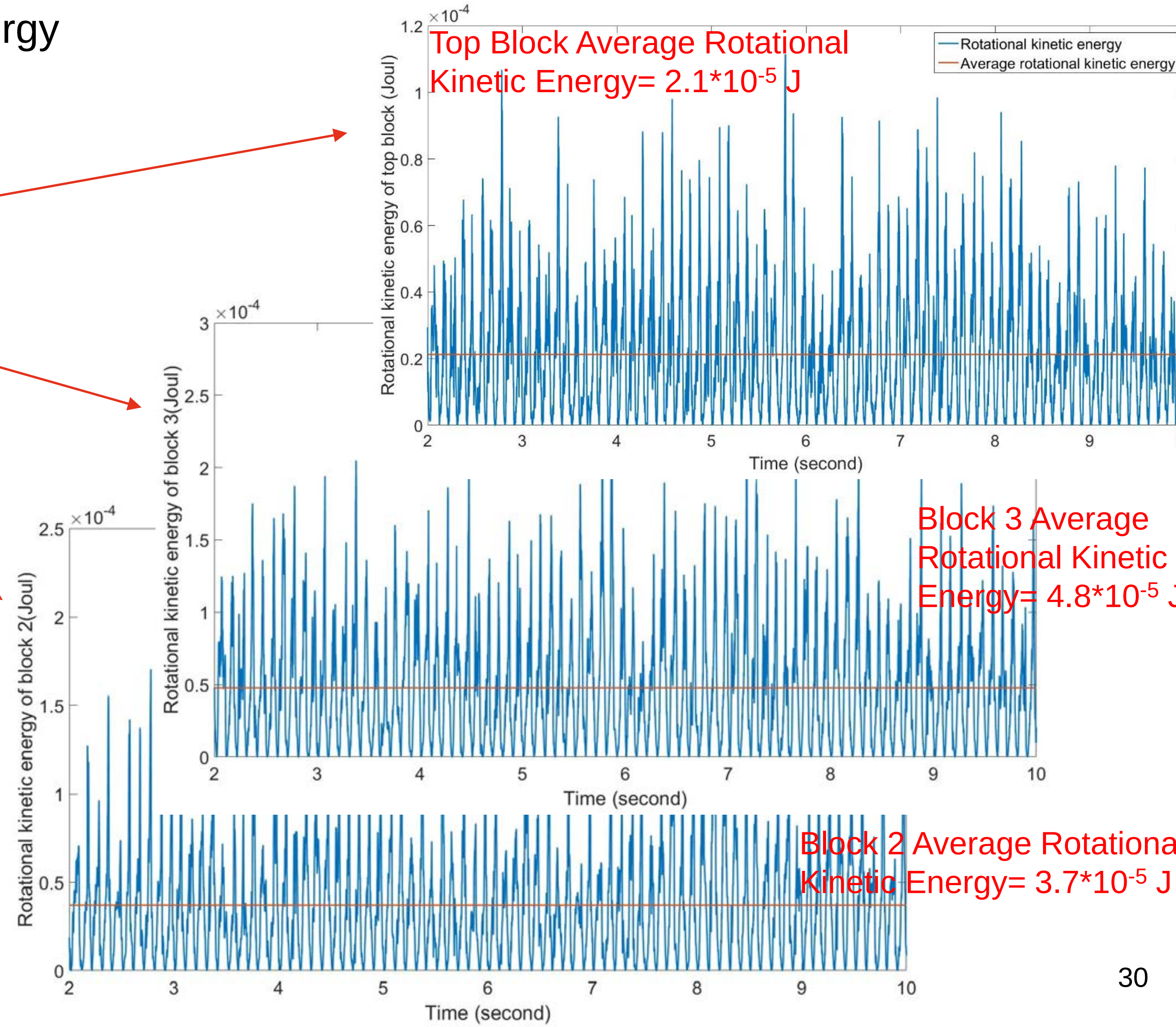




Results and Discussion-
5 blocks column shaking at 5 Hz and 2.5 m/s^2

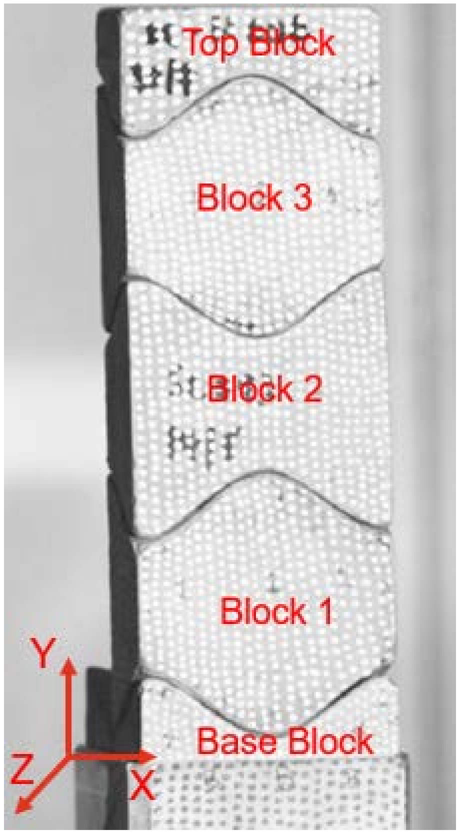
Rotational Kinetic Energy

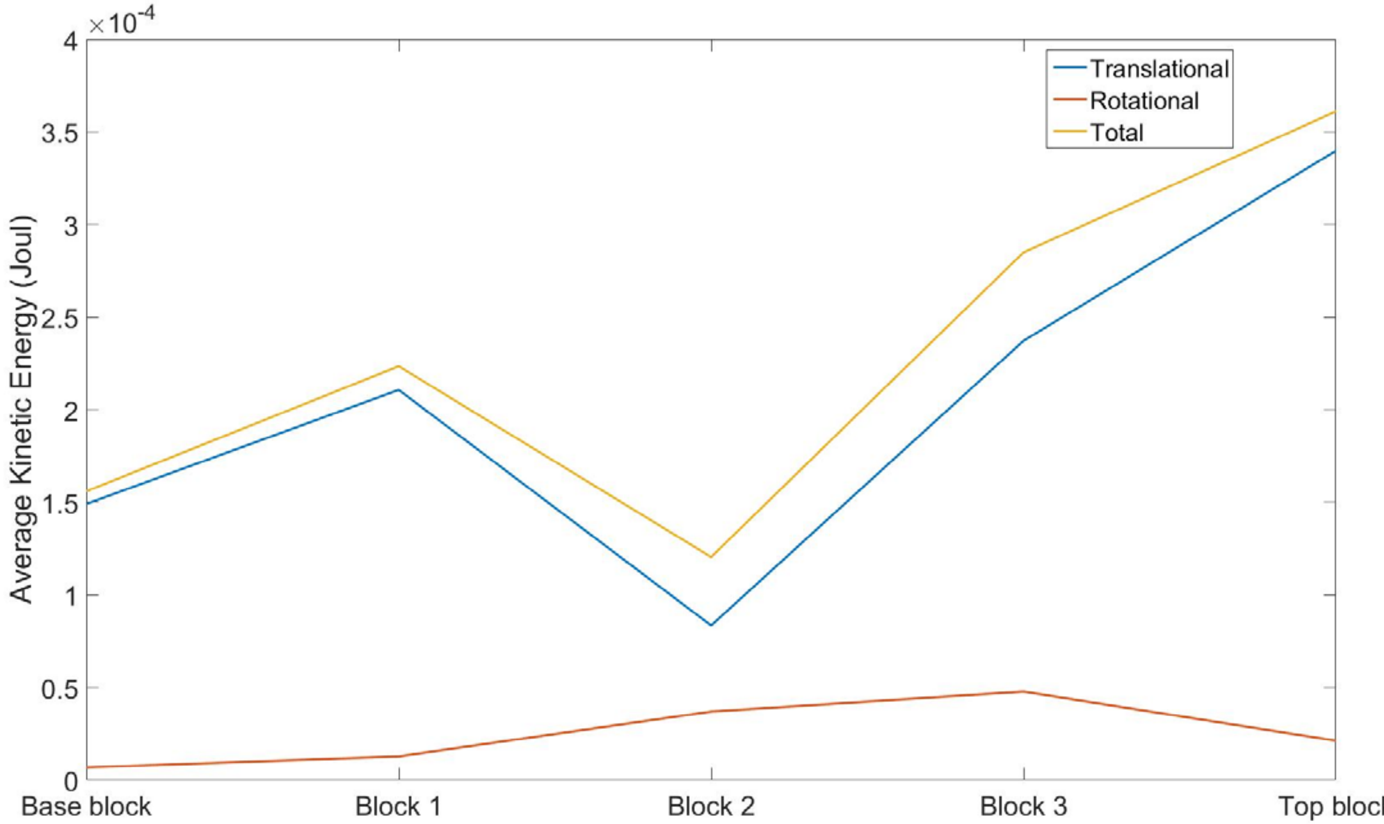




Results and Discussion-
5 blocks column shaking at 5 Hz and 2.5 m/s^2

Kinetic Energy





Results and Discussion-
5 blocks column shaking at 5 Hz and 2.5 m/s^2

Kinetic Energy

- Despite the visible block rocking, the kinetic energy of translational movement dominates

- The total kinetic energy fluctuates around the average kinetic energy for all the blocks

- For top and base blocks which have the same mass and dimensions:
  - The kinetic energy of the top block is higher than the base block

- For blocks 1, 2 and 3 which have the same mass and dimensions:
  - the rotational kinetic energy increases as moving higher position in the column
  - the total or translational kinetic energy are the smallest in block 2 among the three full blocks and the two half blocks, indicating the energy dissipation is most severe near the middle of the column
  - The energy is dissipated through frictional sliding at the interfaces between the blocks

Conclusion

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- The fragmented/blocky geomaterials are modelled using an Osteomorphic block column
- 3D displacement field of each block is recovered with the aid of DIC technique
- A stationary point (centre of the rotational wave) can be seen travelling in the column as the column was shaken at constant acceleration and frequency
- The frequency spectra of the displacements and relative rotation show multiple peaks with the first peak at driving frequency and following peaks at multiple of driving frequencies
- The stationary point and the spectral characteristics obtained from the shaking table experiment on Osteomorphic blocky column are in line with the ones chains of bilinear oscillators show. Therefore, bilinear oscillators are suitable for modelling dynamics of fragmented and blocky geomaterials
- The kinetic energy of the blocks fluctuates around a constant value

Acknowledgements

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The authors acknowledge support from the Australian Research Council through project DP190103260. The authors acknowledge the UWA workshop in developing and manufacturing the experimental setup. In the experiments some setup fixtures previously developed by M. Khudyakov were used. AVD acknowledges the support from the School of Civil and Transportation, Faculty of Engineering, Beijing University of Civil Engineering and Architecture.

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