

TOKYO INSTITUTE OF TECHNOLOGY



GRADUATE DEPARTMENT OF CIVIL ENGINEERING

# ROCKING ISOLATION OF BRIDGES

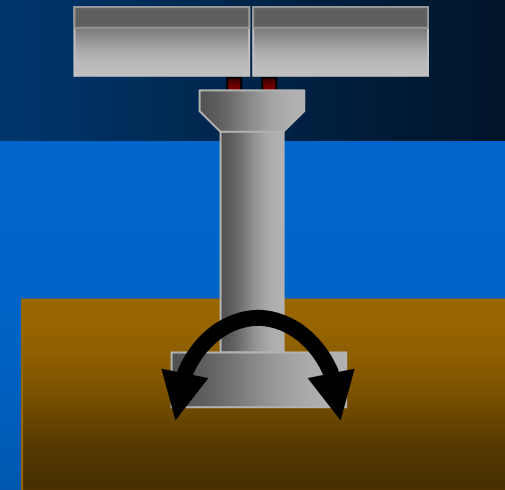
Dimitra SAKELLARAKI

# INTRODUCTION

Direct bridge foundations are **traditionally** designed by **minimizing uplift** from the underlying ground to prevent overturning of the bridge

**HOWEVER...**

Post earthquake inspection of piers has revealed cracks indicating **rocking** during the earthquake



**ADDITIONALLY...**

Analytical studies show that rocking of footing **decreases** the ductility demand at the pier

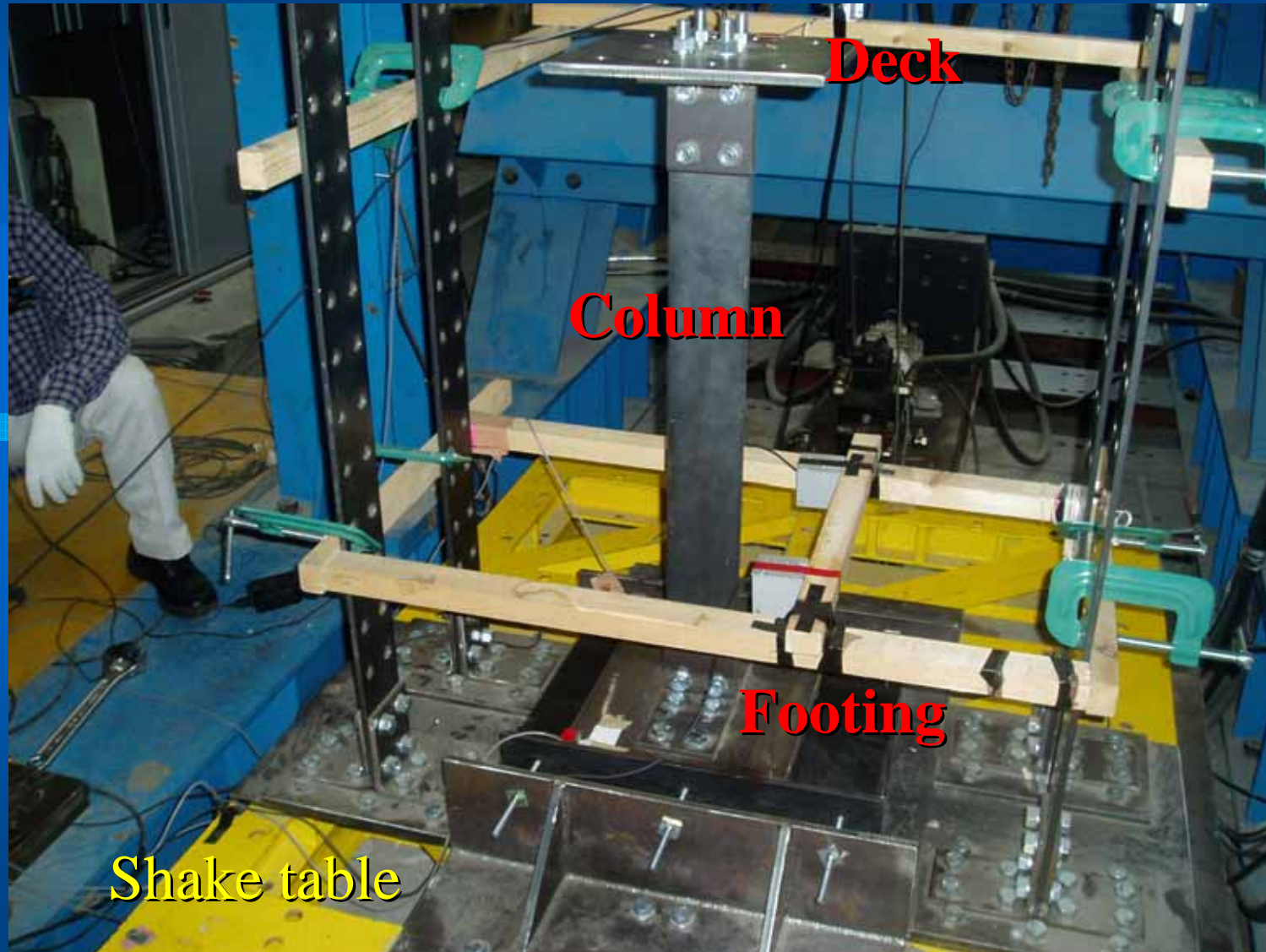
# EXPERIMENTAL STUDY OF ROCKING

An experimental steel model consisting of a **top plate**, a **column** and a **bottom plate** representing a **deck-pier-footing system** is developed. A **rubber block** simulates the ground.

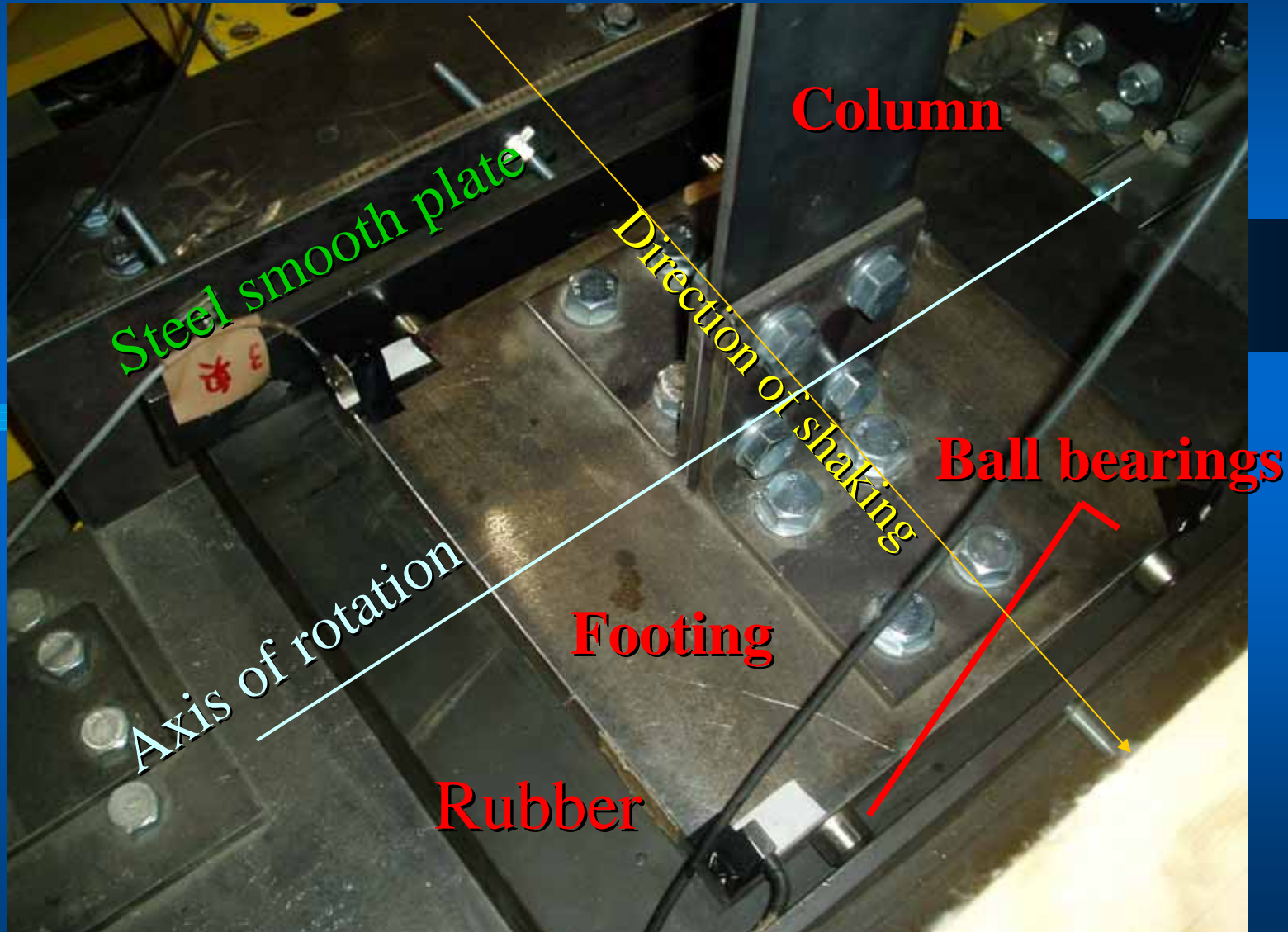
The bridge model is subjected to **shake table tests**.

Sliding of the footing is prevented. **Only rocking** is allowed to happen.

# EXPERIMENTAL MODEL (1)



# EXPERIMENTAL MODEL (2)



# EXPERIMENTAL INVESTIGATION

## MAIN POINTS OF INTEREST

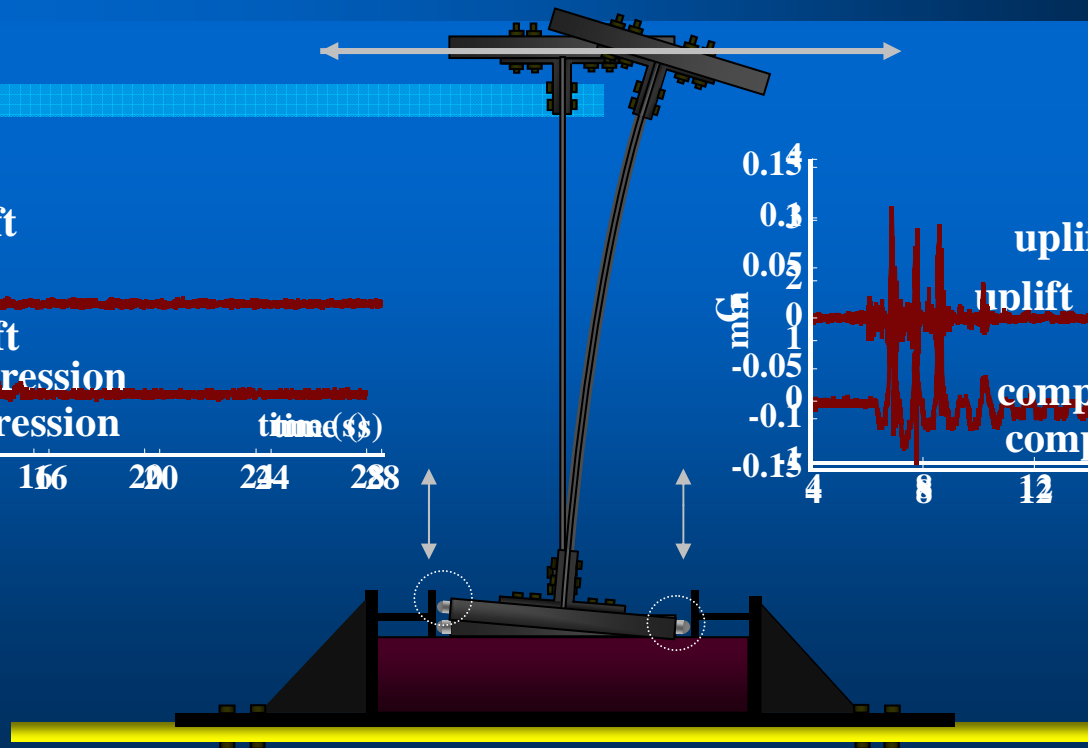
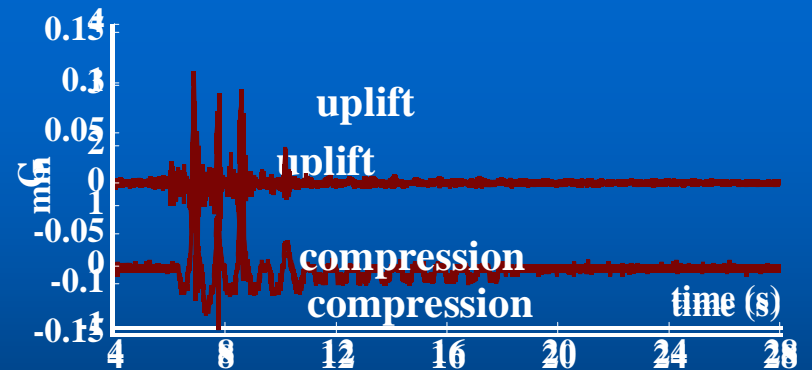
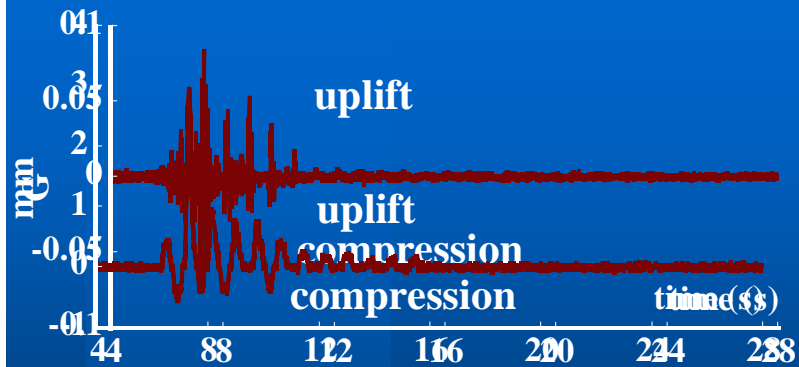
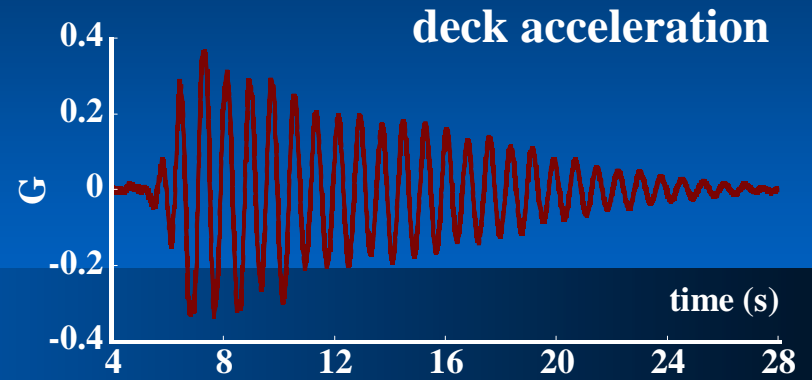
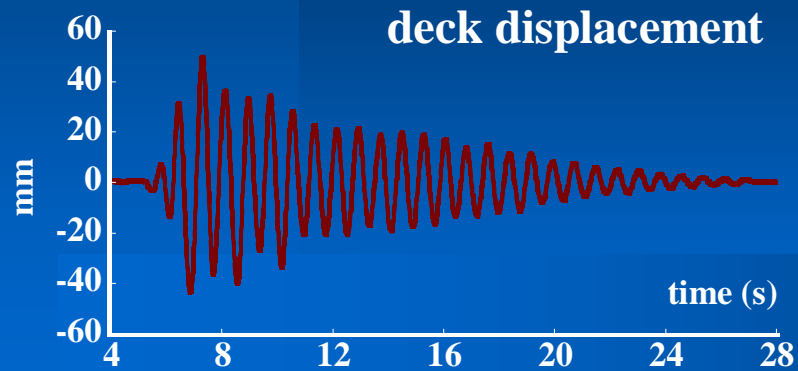
Increase of model's natural period, rotation of the footing, deck displacement, deck acceleration, flexural deformation of the column

## PARAMETERS CONSIDERED

- ✓ effect of deck mass
- ✓ effect of footing size
- ✓ effect of column stiffness
- ✓ effect of ground stiffness

Seismic excitations selected from: Kobe Earthquake (Japan, 1995)  
Duzse Earthquake (Turkey, 1999), Niigata Chuetsu Earthquake (Japan 2004), Northridge Earthquake (USA, 1994)

# MEASURING DIRECTIONS

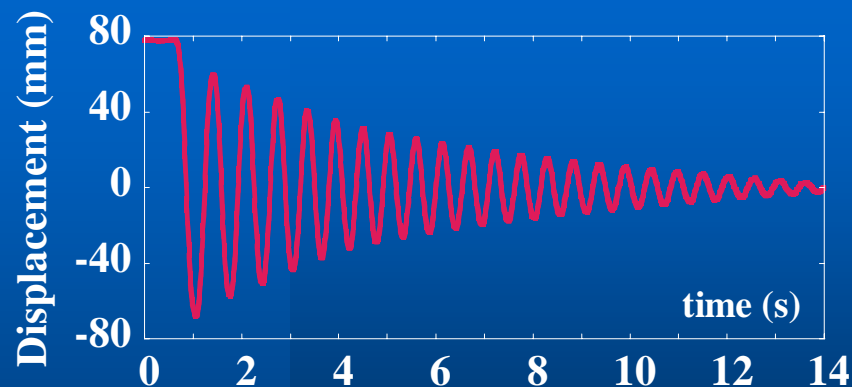


# EXPERIMENTAL PROCEDURE (1)

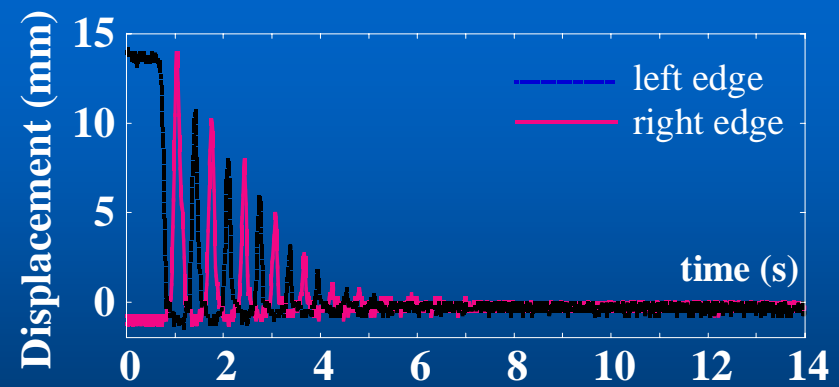
## Free Oscillation Tests

### INFORMATION OBTAINED

- ✓ relationship between natural period  $T$  and footing's uplift
- ✓ equivalent viscous damping ratio



Horizontal displacement  
at the deck



Vertical displacement  
at the footing's edges

# EXPERIMENTAL PROCEDURE (2)

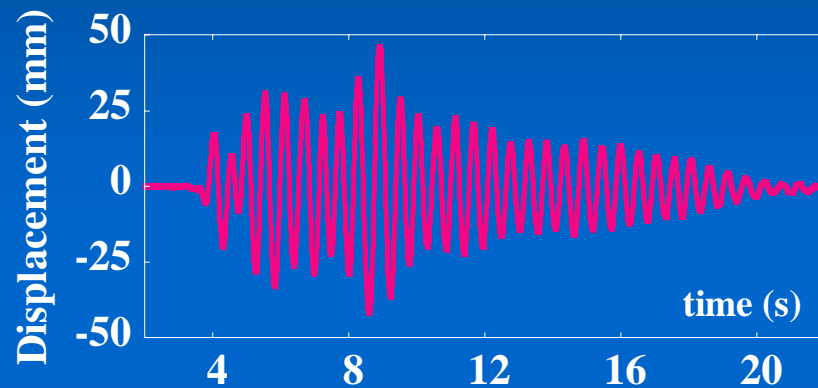
## Shake Table Tests : Kobe JMA 000 30%



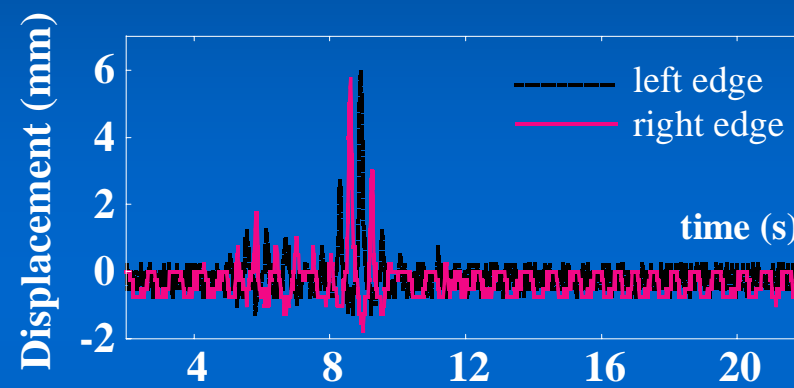
# EXPERIMENTAL PROCEDURE (3)

## Shake Table Tests

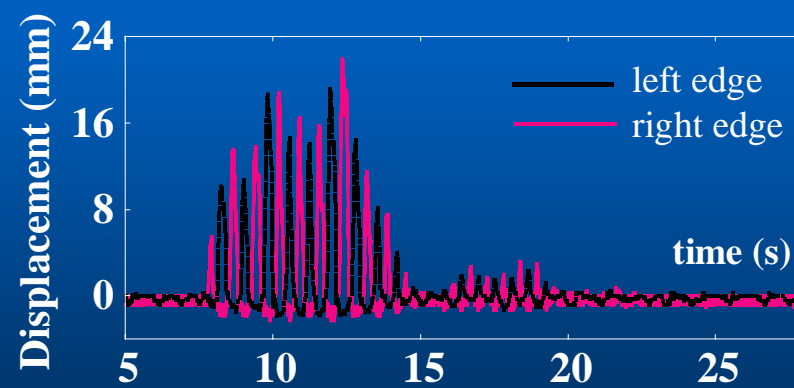
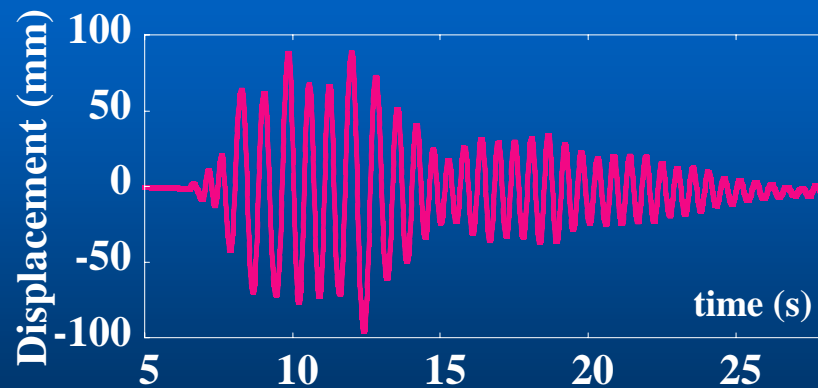
Horizontal displacement  
at the deck



Vertical displacement  
at the footing's edges



Kobe JMA 000 20%



Niigata 019EW 20%

## EXPERIMENTAL PROCEDURE (4)

### Observations based on experimental results

When rocking of bridge pier footings takes place:

- Natural period increases leading to an apparent seismic isolation effect
- Flexural deformation of the pier decreases significantly
- However, deck displacement produced by footing's rotation results in relatively increased overall deck displacement

## EXPERIMENTAL PROCEDURE (5)

### Observations based on experimental results

- Large vertical acceleration develops at the footing's edges during impact with ground indicating danger of soil yielding
- 
- However impact of footing with ground is an extra energy dissipation mechanism which contributes considerably to attenuation of pier's dynamic response

## EXPERIMENTAL PROCEDURE (6)

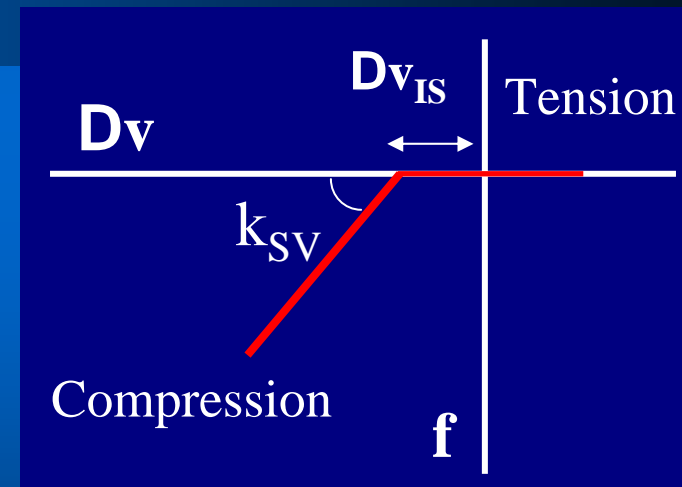
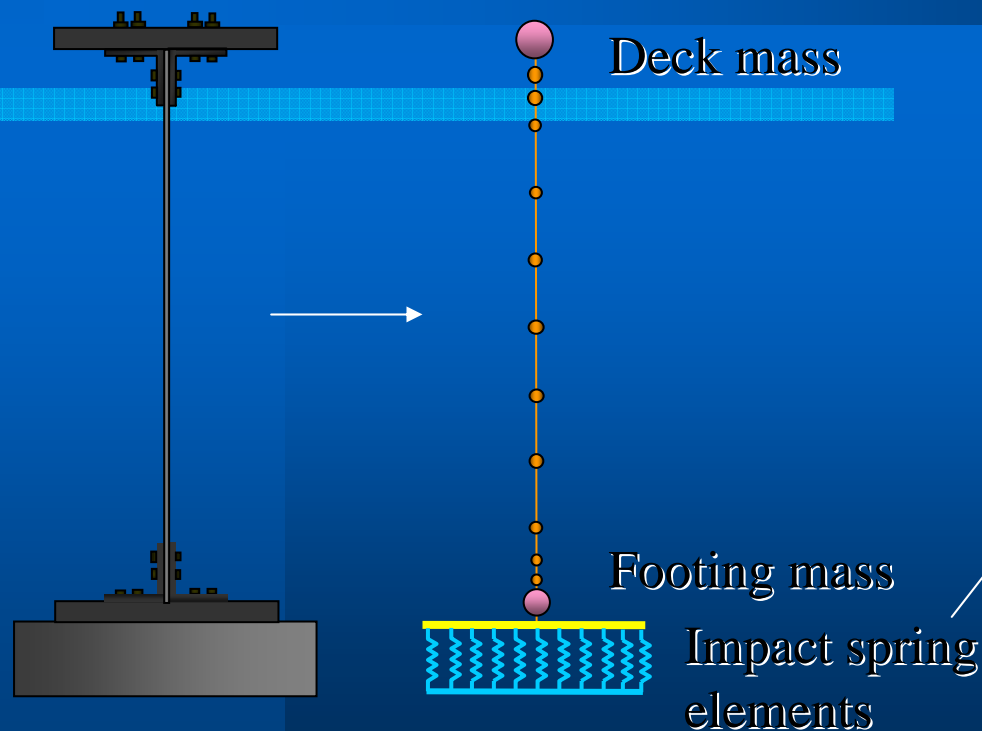
### Regarding the parameters affecting rocking:

- ✓ effect of deck mass : as deck mass increases larger uplift at the footing's edges develops
- ✓ effect of footing size : as footing section decreases larger uplift at the footing's edges develops
- ✓ effect of column height : uplift at footing's edges decreases drastically for short columns
- ✓ effect of ground stiffness : depending on the ground motion, stiffer ground generates smaller or larger uplift

# ANALYTICAL PROCEDURE

A discrete model idealizes the model bridge:

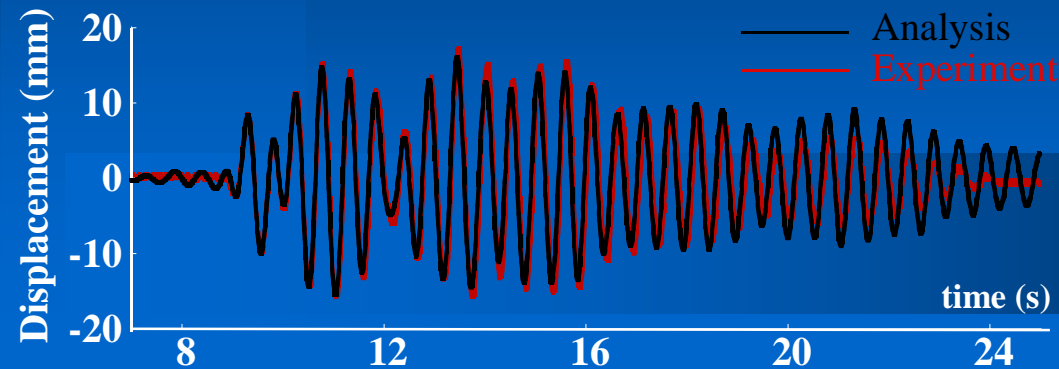
- Linear beam elements for the column
- Rigid elements for the footing
- Spring elements for footing's separation and contact with rubber



$k_S$  : stiffness of spring element  
 $D_{vIS}$  : initial displacement due to the dead weight

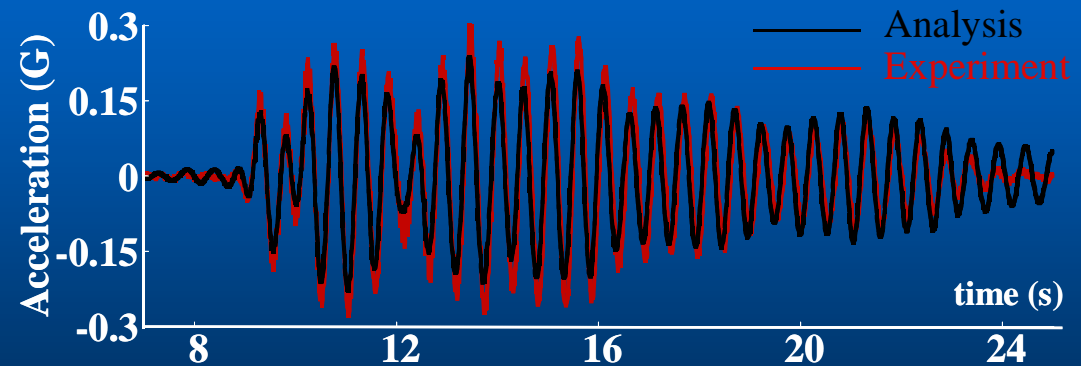
# CORRELATION WITH EXPERIMENTAL DATA(1)

## Model response without uplift



LINEAR CASE

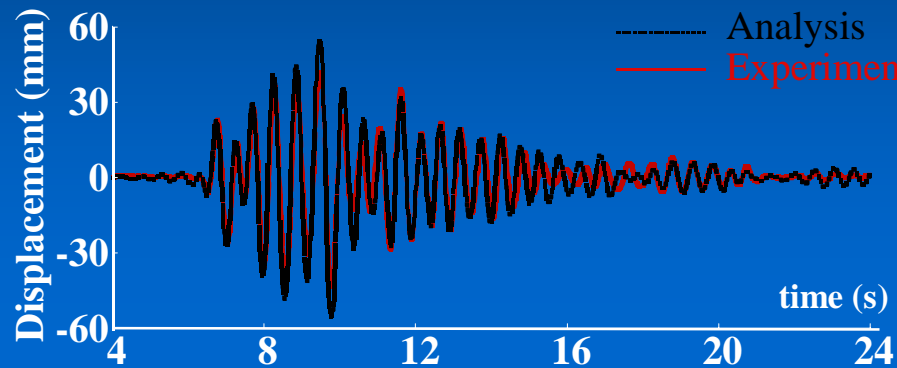
## Horizontal displacement at the deck



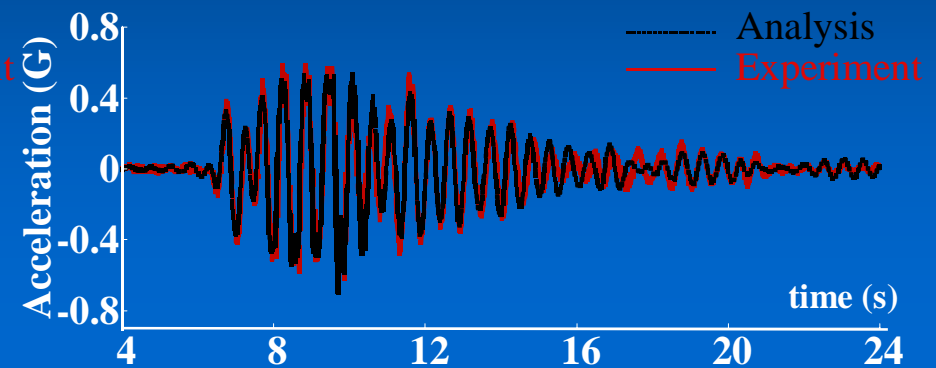
## Horizontal acceleration at the deck

# CORRELATION WITH EXPERIMENTAL DATA(2)

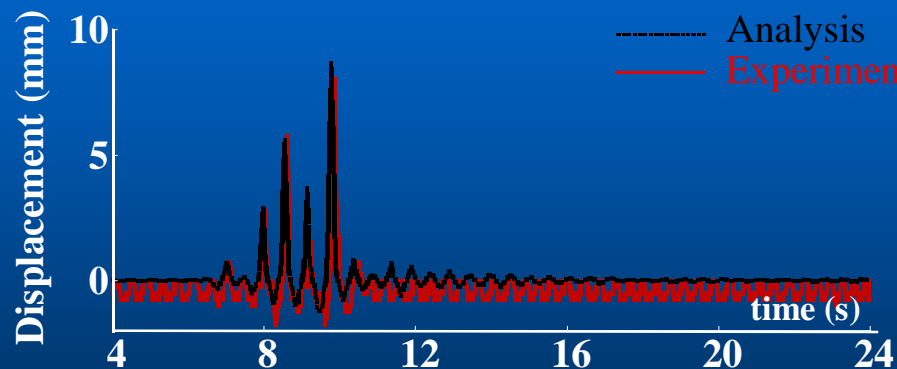
## Model response with uplift



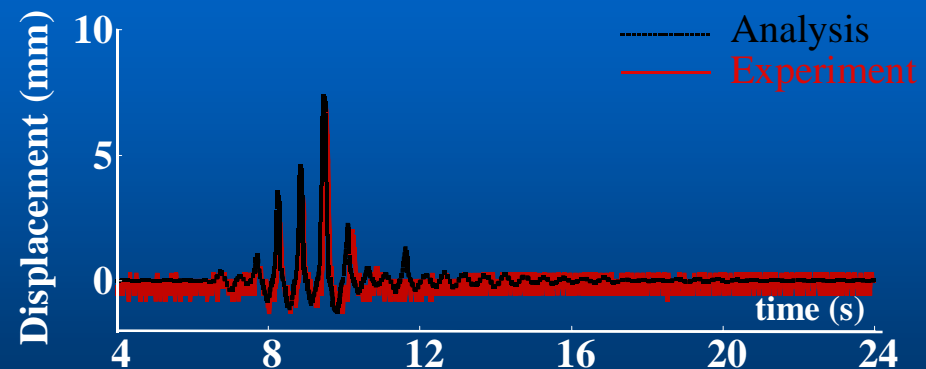
Horizontal displacement  
at the deck



Horizontal acceleration  
at the deck



Vertical displacement  
at the left edge of the footing



Vertical displacement  
at the right edge of the footing

# CONCLUSIONS OF ANALYTICAL PROCEDURE

- Analysis gives very good correlation between experimental and computed response if uplift obtains relatively small or medium values
- If uplift with relatively large values occurs conventional analytical tools cannot simulate accurately increase of period due to rocking response, leading to underestimation of footing's uplift and deck displacement. Software taking P- effect into account must be used.

THANK YOU FOR YOUR KIND ATTENTION