Numerical and Experimental Study of the Impact of the Plastic Hinge Formation in Extended Pile-Shaft Supported Bridge

Mohammad A. **MAHMOUD**
[MMahmoud.a@outlook.com]
Dr Alessandro TOMBARI
[A.Tombari@brighton.ac.uk]
University of Brighton

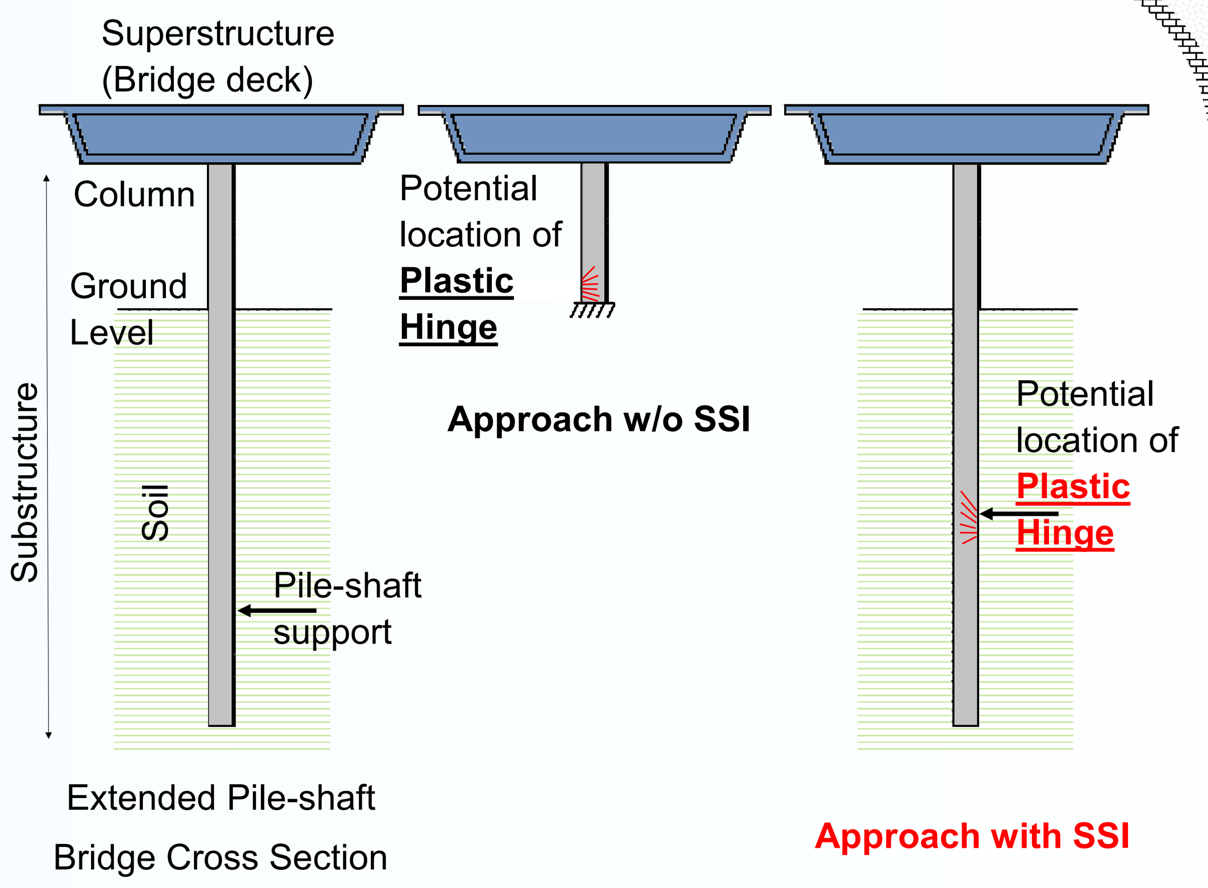
I. Introduction

Plastic Hinge formation in relation to SSI

Extended Pile-Shaft Supported Bridge is characterized by the type of foundation where the column is continued below the ground level as a pile shaft of approximately the same diameter.

Increase in flexibility due to compliance of the foundation can be observed under dynamic loadings, where severity of the lateral displacement could cause structural collapse from plastic hinge formation along the height of the subsection of the bridge. Therefore, accounting for Soil-Structure Interaction (SSI) becomes fundamental for the design of extended pile shaft type bridges.

Plastic hinge is a yielding region where it develops in a structural element at the point of bending moment at its maximum, where the element is subjected to loads producing huge sum of strain at yield stress.



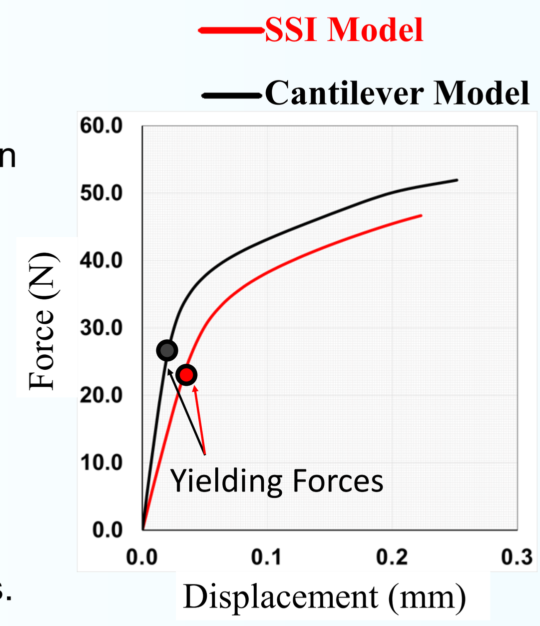
Positioning of plastic hinge formation and it's impact in Extended Pile-Shaft Bridges?

II. Prototype Design

Incremental Dynamic Analysis (IDA) has been accomplished through experimental and numerical analyses.

Push Over Analysis (Displacement Control Analysis):

- Due to the Shaking-Table's maximum acceleration restricted to 2g, preliminary non-linear push over analyses (FEM) has been conducted to calculate maximum Yielding Force.
- Yielding Force has been used to design experimental assemblies, including dimensions and cross sections.



- From FEM - mass of 2.5 kg on the top as Superstructure is designed from the Yielding Forces. This is to produce sufficient acceleration to reach yielding in the structure once excited.

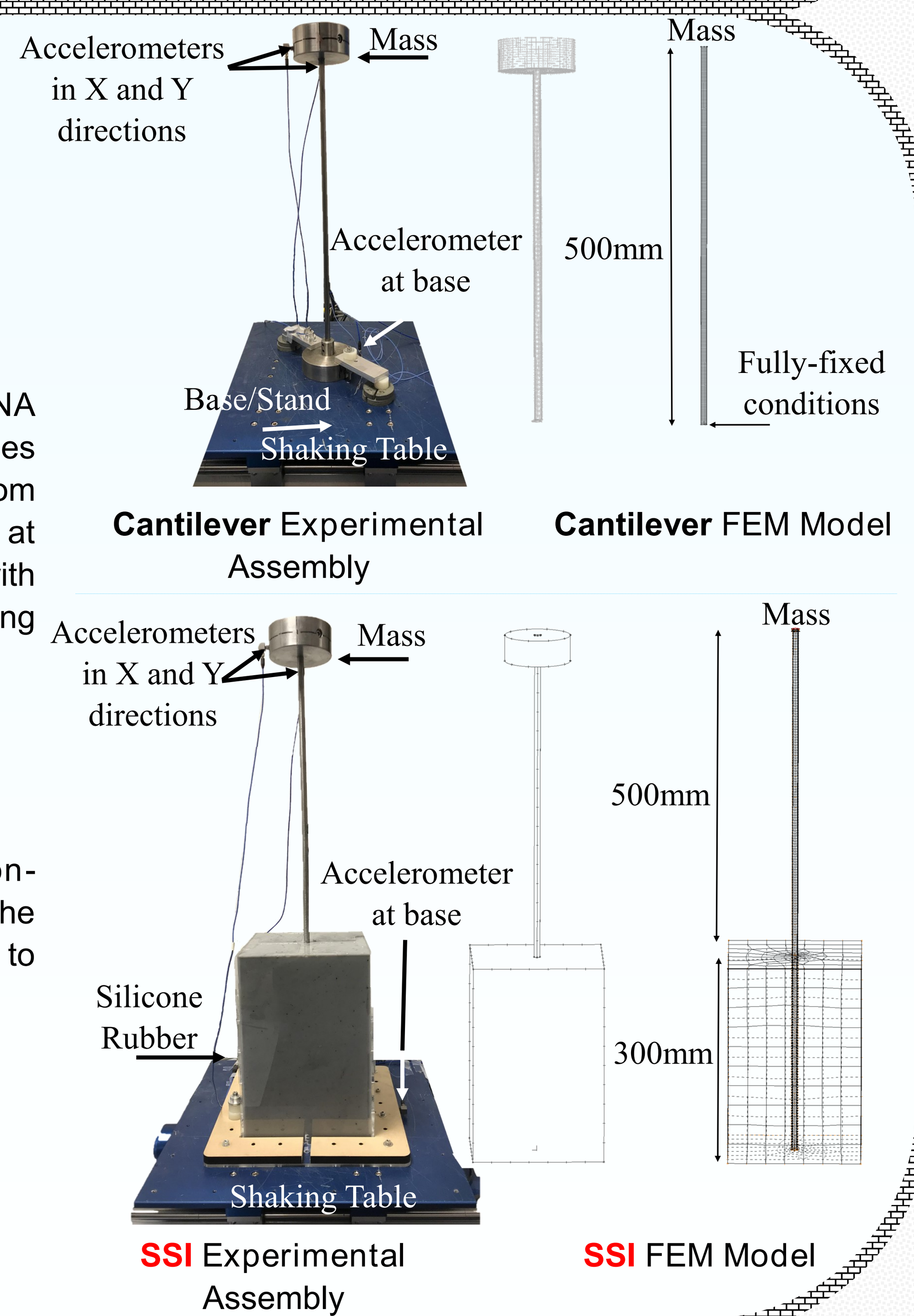
III. Experimental and Numerical Set-up

Experimental Incremental Dynamic Analysis (EIDA)	Numerical Incremental Dynamic Analysis (NIDA)
Cantilever Model: Consisting of a steel tube with diameter of 10mm and thickness of 1m with length of 500mm above the stand to the top. Mass of 2.5kg fixed on top. Assembly fixed to the shaking table - satisfying fully-fixed conditions.	**Cantilever Model:** FEM in ADINA software with non-linear material properties assigned to the model - intensities from EIDA identical to measured acceleration at base/shaker. Time-History analyses with mass concentration function (replicating mass of 2.5kg).

- Harmonic signal with incremental amplitude and frequency of 3.8Hz.

SSI Model: Identical steel tube with same dimensions as the cantilever model - 300mm of length embedded in silicone to satisfy SSI conditions with 500mm of length above the silicone rubber. With the same mass of 2.5Kg fixed to the top of the steel tube.	**SSI Model:** FEM in ADINA, where non-linear material properties were given to the steel tube embedded in silicone rubber to predict SSI conditions.

- Harmonic signal with incremental amplitude and frequency of 2.8Hz.

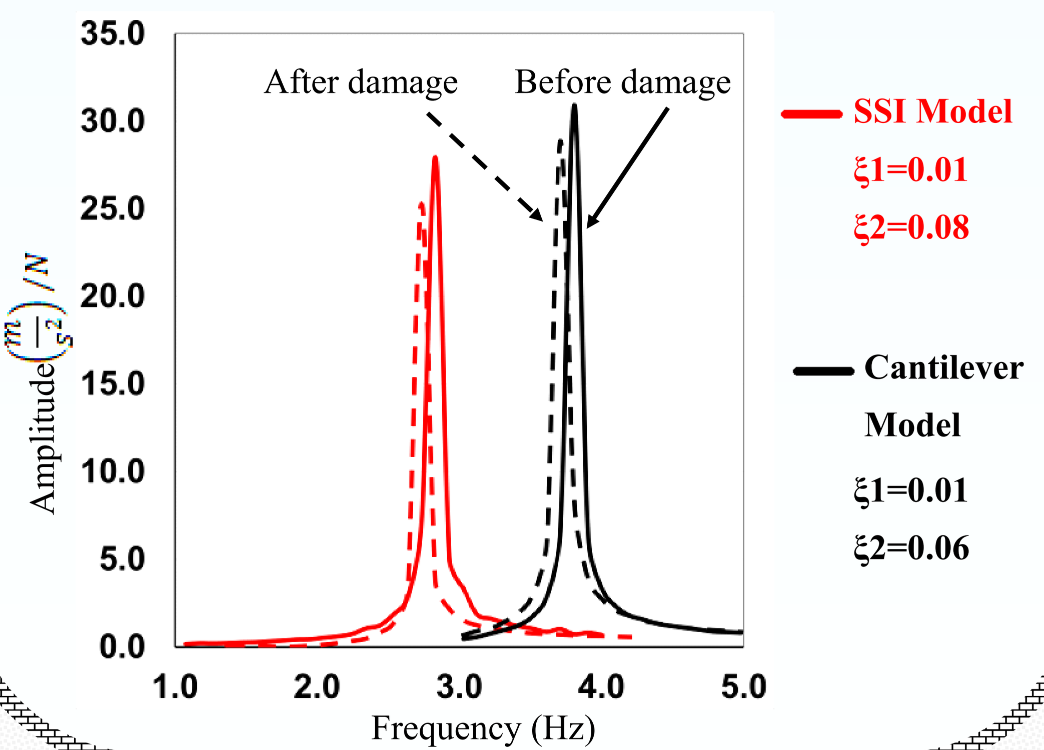


IV. Modal Testing

Impact Hammer Testing is carried out for **Cantilever Model** and **SSI Model** - before and after damage.

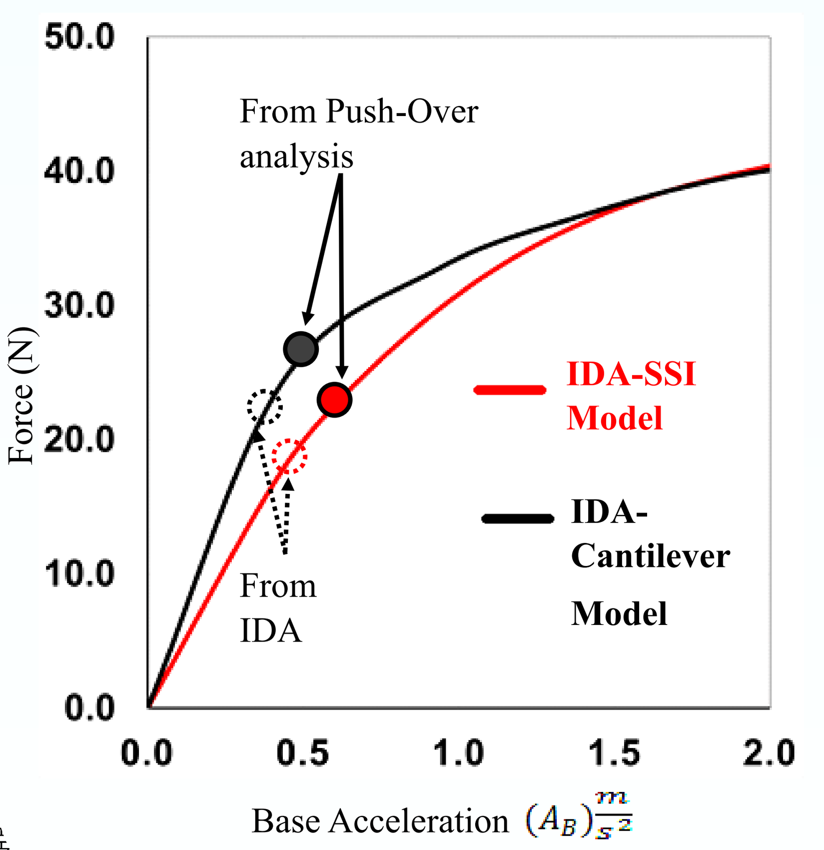
Main observations are:

- Natural frequency of the SSI model is less than the cantilever model due to Soil-Structure Interaction phenomenon.
- After damage frequency decreases due to accumulation of plastic deformation.
- Damping ratio (ξ) increases after damage.

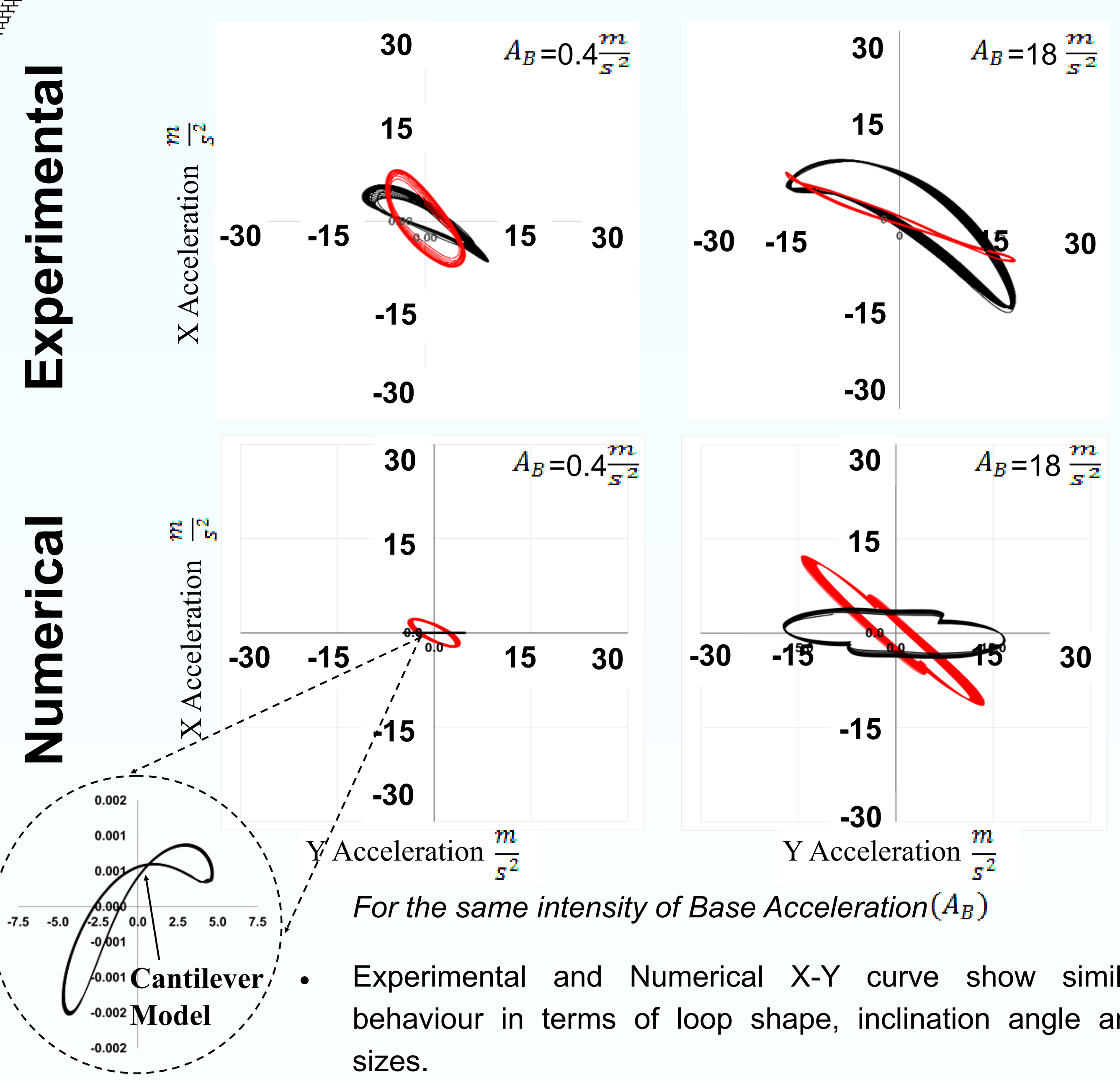


V. Experimental IDA Curve

- Tests are performed for 16 increments - where shaking table's acceleration varied from 0.4 to 18 m/s^2, with fixed frequency for both models.
- Force for each test is obtained from measured acceleration of the Superstructure multiplied by the total mass and plotted against measured acceleration of the base.
- Yielding Force for **SSI Model** occurs earlier than for the **Cantilever Model**.



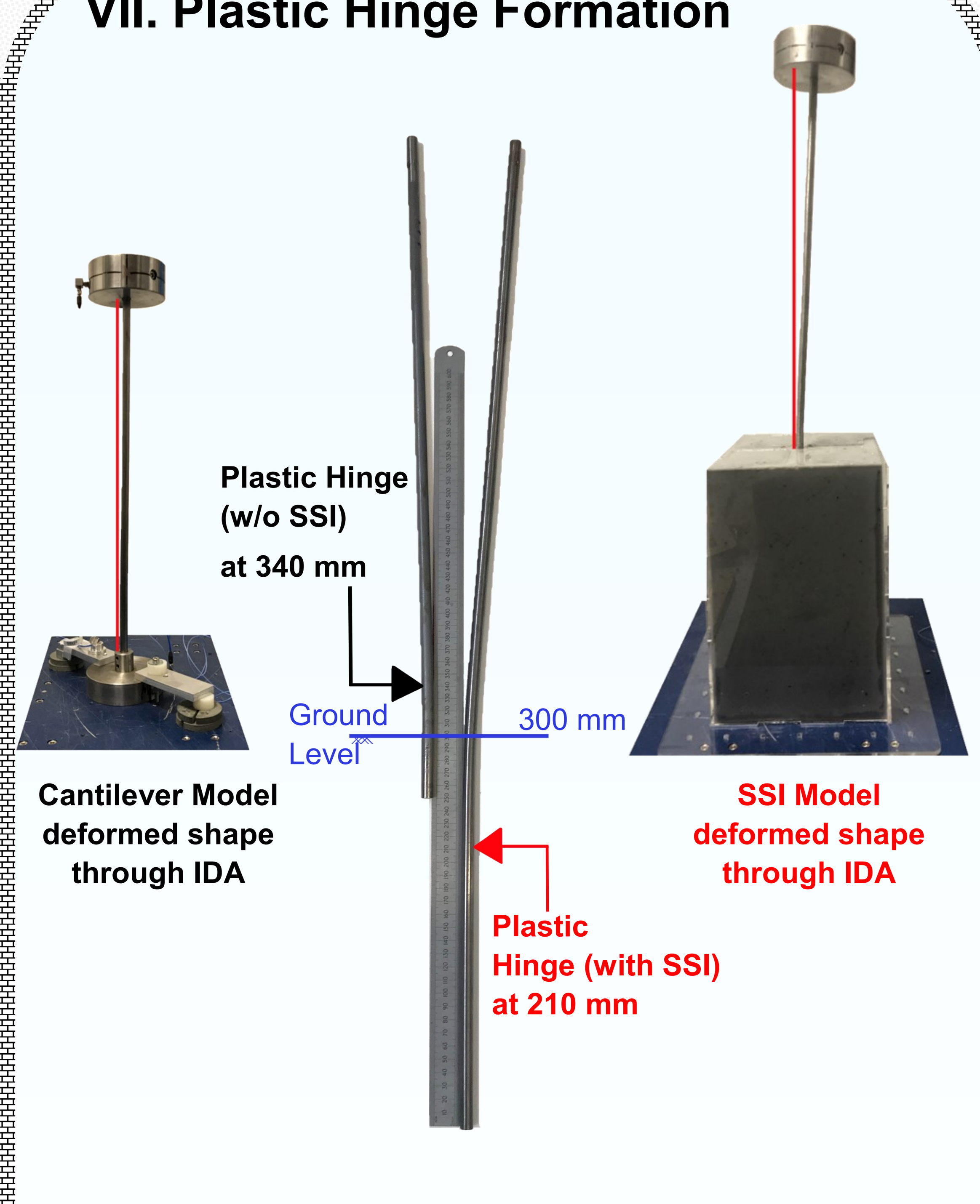
VI. Acceleration X-Y Curves



For the same intensity of Base Acceleration (A_B)

- Experimental and Numerical X-Y curve show similar behaviour in terms of loop shape, inclination angle and sizes.
- Experimental X-Y loop of **Cantilever Model** has greater angle of inclination in comparison to the FEM due to imperfection in the assembly such as the composition of the steel tube.
- Both Experimental and Numerical X-Y curves for **SSI Model** show a decrease in loop size for higher intensity of base acceleration, whereas, loop size is increasing for the **Cantilever Model**.

VII. Plastic Hinge Formation



The **SSI Model** deforms larger to the **Cantilever Model** with plastic hinge region starting at depth below the ground level (i.e. contained within the silicone rubber) when Soil-Structure Interaction is accounted for.

Extended pile-shaft type bridge under dynamic loadings produce plastic hinge positioned along the height of the pile below the soil. A structural analysis without considering SSI will result in a non-conservative design - hence, structural failure could be the consequence.

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The Institution of Structural Engineers