SMART Shear Keys to Restrain Bridge Girder Movement during Earthquakes and Tsunami

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- **Design Concept**

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- **Simulation and Results**

  Pushover analysis, force-displacement curve

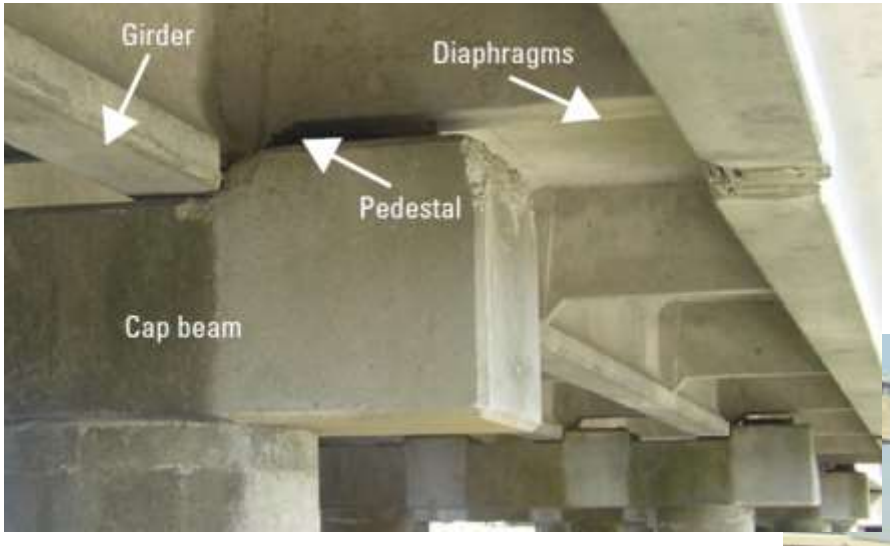
- **Experimental Tests**

- **Concluding Remarks**

INTRODUCTION

- **Earthquake/Tsunami Reconnaissance**

  I-10 Twin Span Bridge, 2005 Hurricane Katrina



Diaphragms and girders underneath the bridge decks create a concrete "box" facing downward (left) .

Interstate 10 Twin Span Bridge's causeway approach spans dropped off of bent cap beams (right).

Chen, G., Witt III, E. C., Hoffman, D., Luna, R., & Sevi, A. (2005). Analysis of the Interstate 10 twin bridge's collapse during Hurricane Katrina. Science and the storms—the USGS response to the hurricanes of, 35-42.

INTRODUCTION

- **Earthquake/Tsunami Reconnaissance**

  Miaoziping Bridge, 2008 Wenchuan Earthquake

Yen, W. P., Chen, G., Yashinski, M., Hashash, Y., Holub, C., Wang, K., & Guo, X. (2009). Lessons in bridge damage learned from the Wenchuan earthquake. Earthquake Engineering and Engineering Vibration, 8(2), 275-285.

INTRODUCTION

- **Earthquake/Tsunami Reconnaissance**

  2010 Chile Earthquake

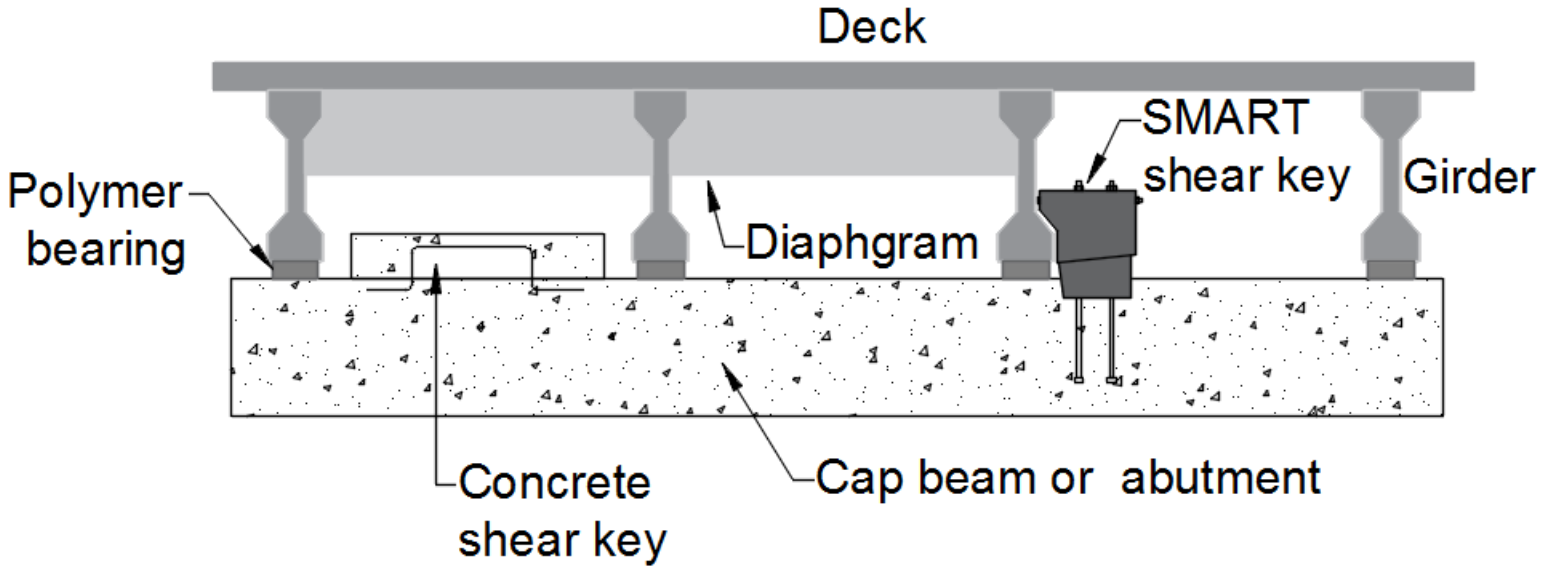
Llacolén bridge with internal concrete key (left)

The Westbound Independencia bridge with external shear key (right)

Chen, G., Yen, P. W., Buckle, I., Allen, T., Alzamora, D., Ger, J., & Arias, J. G. (2010). 2010 Chile Earthquake implications to the seismic design of bridges. In Proceedings of the 26th US-Japan Bridge Engineering Workshop (pp. 203-216).

DESIGN CONCEPT

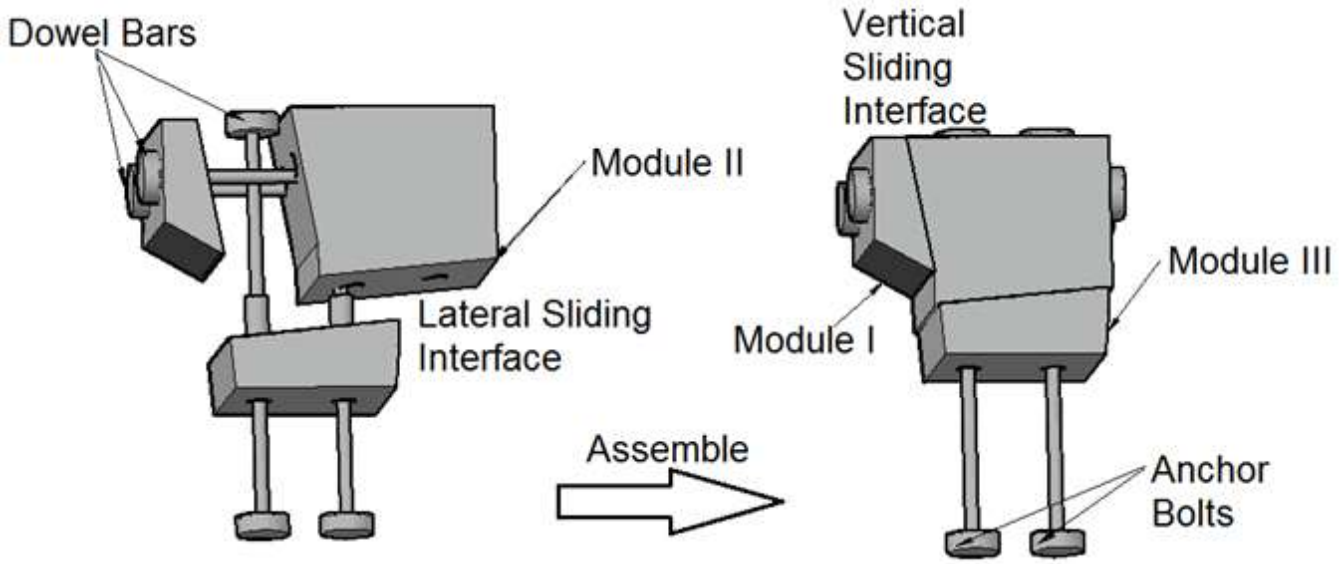
- **SMART Shear Key Design**



Design features and objectives: 1.Sliding 2.Modular 3.Adaptive, 4.Replaceable 5.Two-dimensional

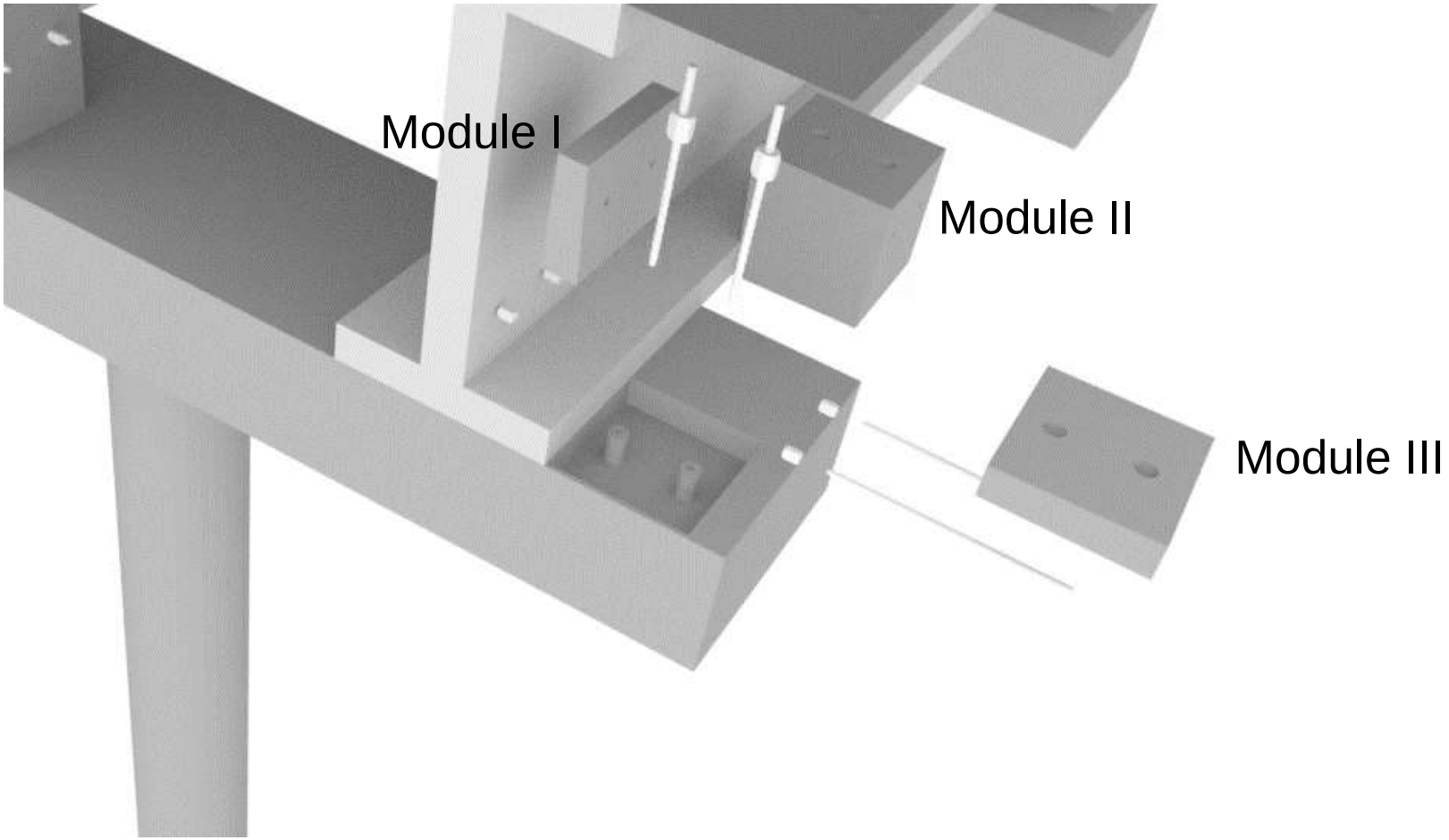
DESIGN CONCEPT

- **SMART Shear Key Assembly**



Assemble three concrete modules via dowel bars and install the SMART shear key on bridges via cast-in anchor bolts in the bridge cap beam or abutment.

DESIGN CONCEPT



SHEAR-RESISTANCE MECHANISM

- **SMART Shear Key Shear-resistance Mechanism**

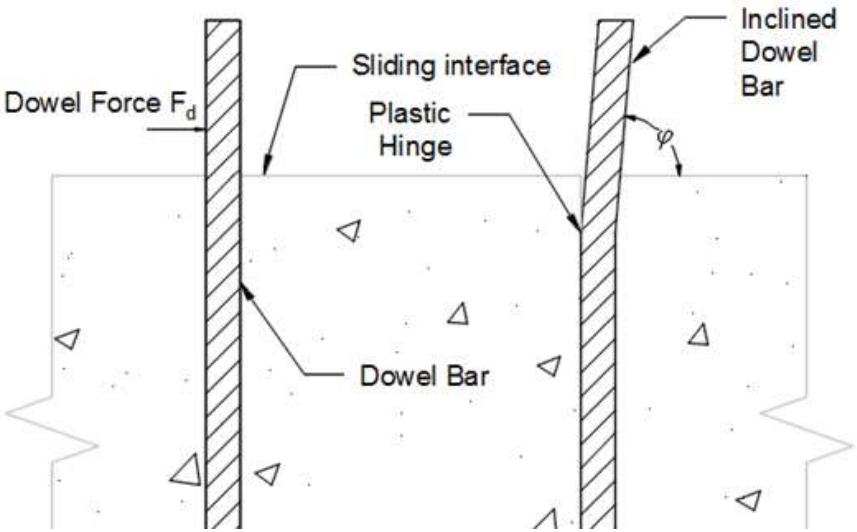
  - ✓ Dowel action of reinforcing bars crossing the interface
  - ✓ Kinking effect of dowel bars
  - ✓ Aggregate interlock

  Dowel action, kinking effect of dowel bars and aggregate interlock constitute the three main sources of the shear-resistance mechanism of the SMART shear key

SHEAR-RESISTANCE MECHANISM

- **SMART Shear Key Shear-resistance Mechanism**

  ✓ Dowel action of reinforcing bars crossing the interface

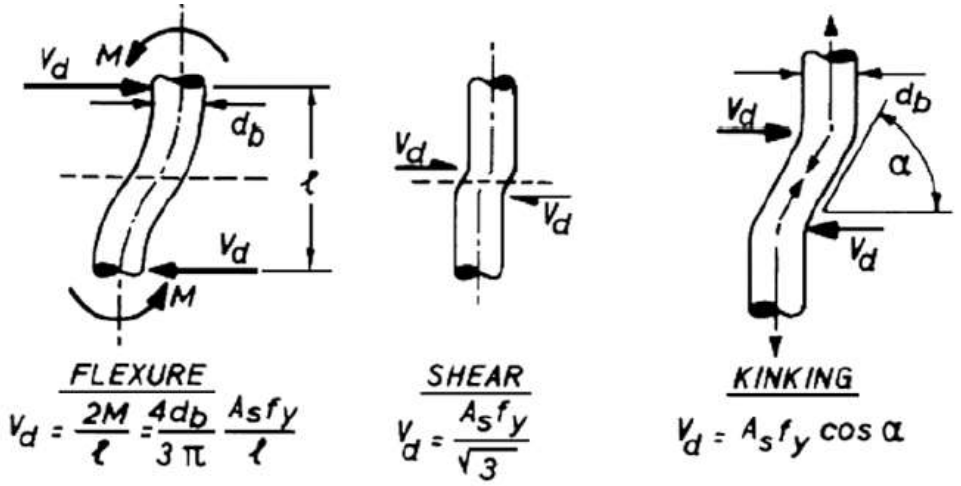


Dowel action is that the dowel bar compresses surrounding concrete.

SHEAR-RESISTANCE MECHANISM

- **SMART Shear Key Shear-resistance Mechanism**

  ✓ Kinking effect of dowel bars



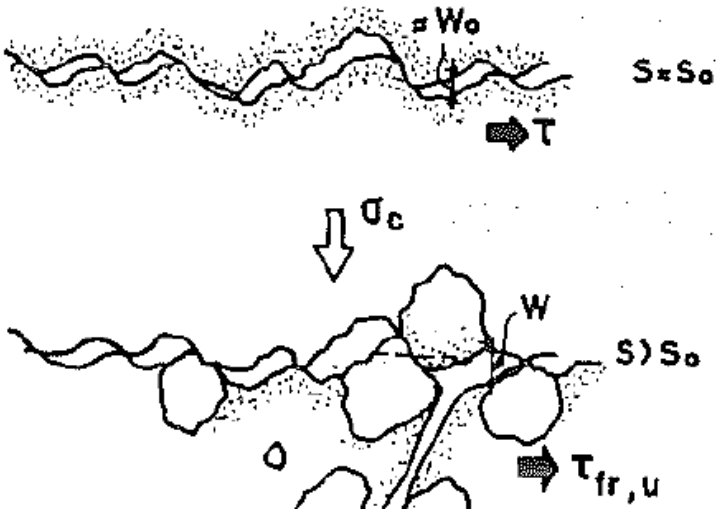
Kinking effect of dowel bars comes from the large deformation of dowel bars when they compress the surrounding concrete.

Paulay, T., Park, R., & Phillips, M. H. (1974). Horizontal construction joints in cast-in-place reinforced concrete. Special Publication, 42, 599-616.

SHEAR-RESISTANCE MECHANISM

- **SMART Shear Key Shear-resistance Mechanism**

  ✓ Aggregate interlock



Aggregate interlock originates from the protruding particles on the interface between concrete blocks.

Tassios, T. P., & Vintzēleou, E. N. (1987). Concrete-to-concrete friction. Journal of Structural Engineering, 113(4), 832-849.

SIMULATION AND RESULTS

- **SMART Shear Key Numerical Simulation**

  ✓ Dimension, material properties

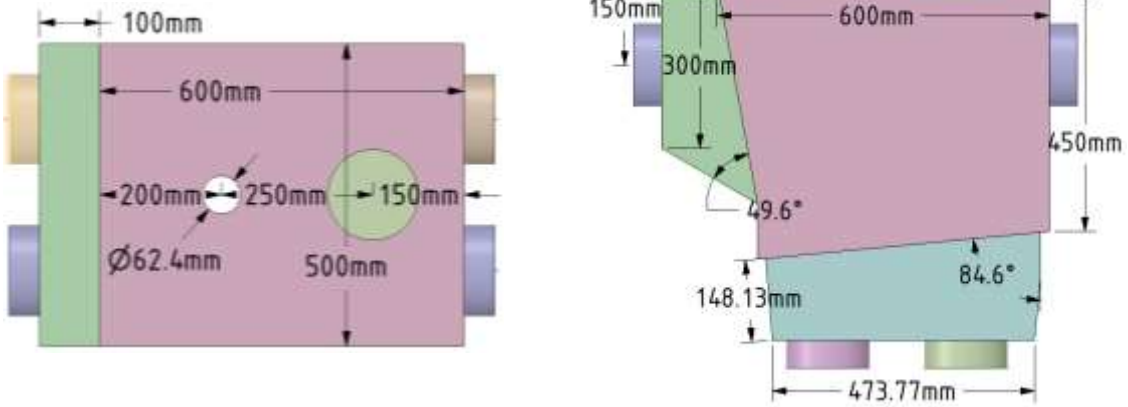
  ✓ Numerical model

  ✓ Results analysis

SIMULATION AND RESULTS

- **SMART Shear Key Numerical Simulation**

  ✓ Dimension, material properties



(a) Plan view (b) Front view

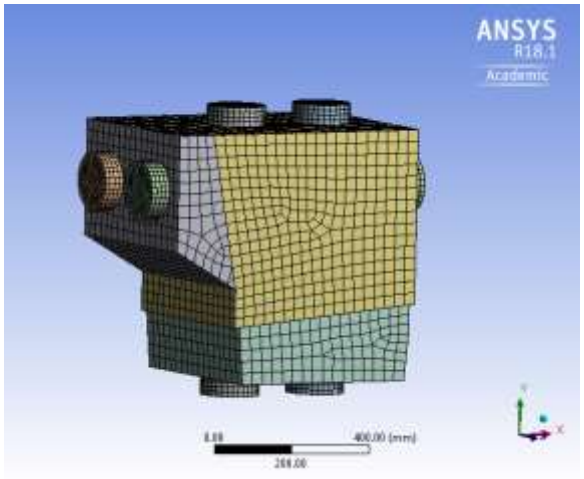
Piece	Material	Young's (MPa)	Yield Str. (MPa)	Poisson ratio	Nonlinearity
Concrete	UHPC	42000	100	0.19	elastic-plastic
Dowel bar	DYWIDAG	200000	1000	0.3	elastic-plastic

Note: 1. UHPC is short for ultra-high performance concrete.

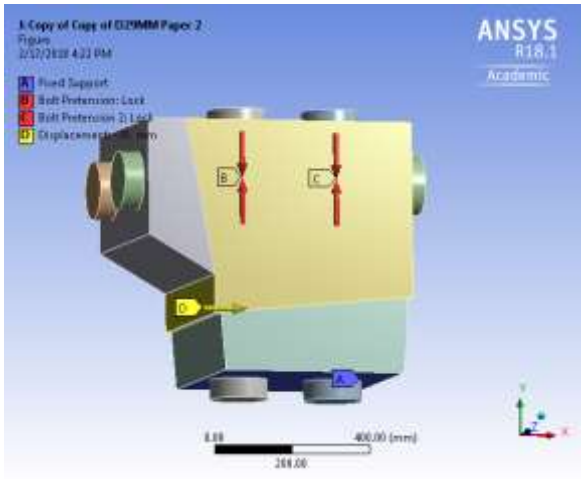
ACCOMPLISHMENT

- **SMART Shear Key Numerical Simulation**

✓ Numerical model



(a) Mesh



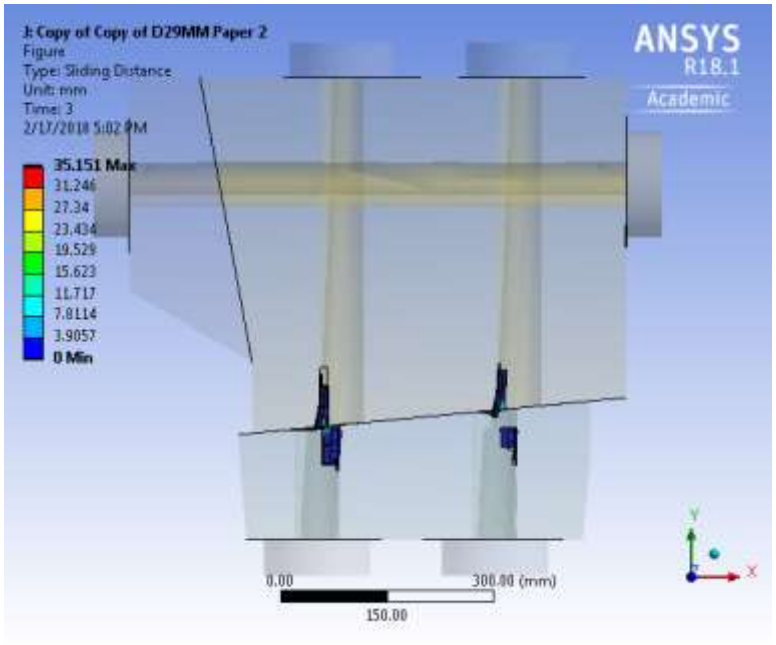
(b) Load and Boundary

Boundary: the bottom of Module III was fixed, labeled as A in Figure (b).
Load: two bolt pretensions 1000N were applied to the vertical dowel bars, labeled as B and C in Figure (b). A displacement up to 35mm was applied to the left surface of Module II, labeled as D.
Friction: the friction coefficient of the interface between Module II and Module III is set to be 0.3.

SIMULATION AND RESULTS

- **SMART Shear Key Numerical Simulation**

  ✓ Results analysis

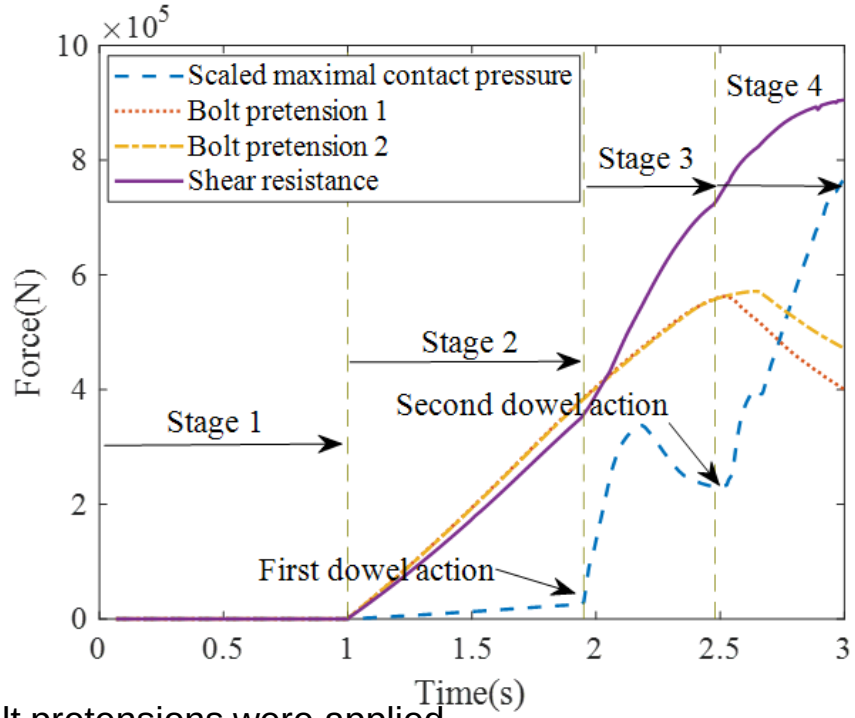


Deformation of the dowel bars and sliding of Module II were shown in the figure above as well as the compression of dowel bars on the surrounding concrete. Due to the sliding, the loosely fit-up gap between dowel bars and concrete was closed.

SIMULATION AND RESULTS

- **SMART Shear Key Numerical Simulation**

  ✓ Results analysis



Stage 1: 1000N bolt pretensions were applied.

Stage 2: The push displacement on Module II started. The resistance force against the push displacement started to increase.

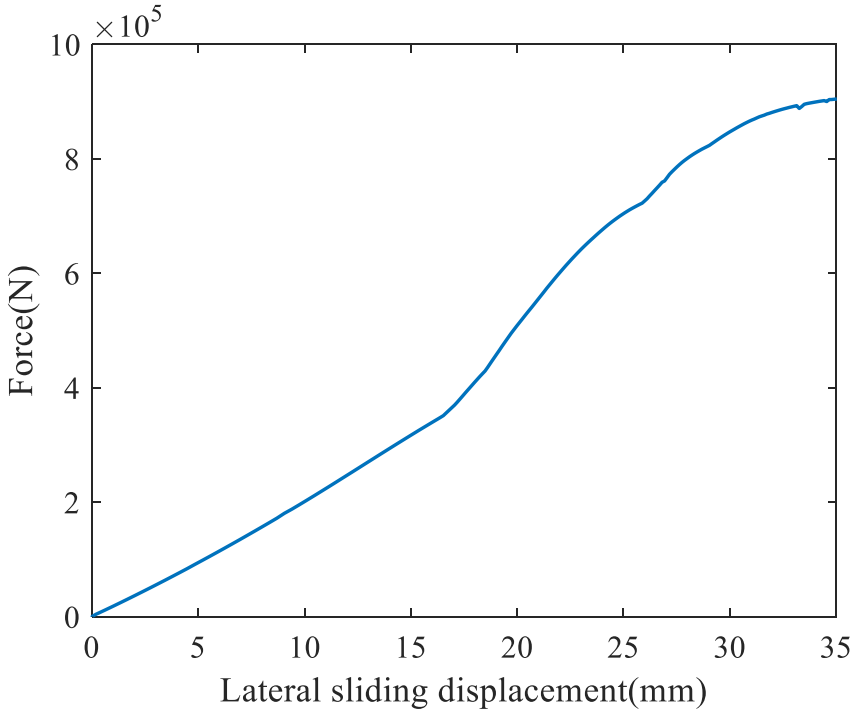
Stage 3: The dowel bars contacted and compressed the surrounding concrete in Module II.

Stage 4: The dowel bars contacted and compressed the surrounding concrete in Module III.

SIMULATION AND RESULTS

- **SMART Shear Key Numerical Simulation**

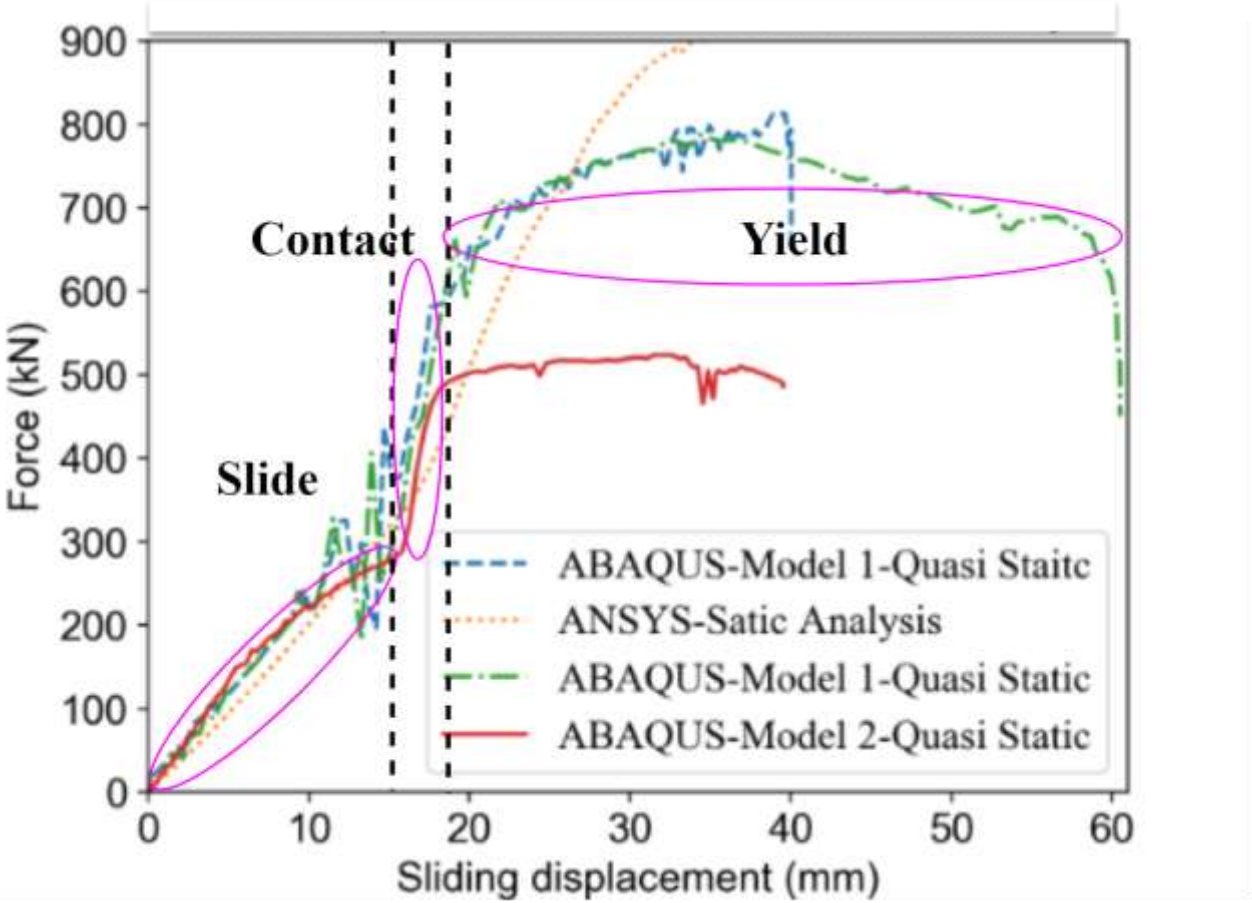
  ✓ Results analysis



The force-displacement curve shows that the SMART shear key has a very good adaptability to the movement of bridge girders and an outstanding load capacity close to 1000000N when the movement is excessive.

SIMULATION AND RESULTS

- **SMART Shear Key Numerical Simulation**
  - **Force-displacement curve of a SMART shear key**

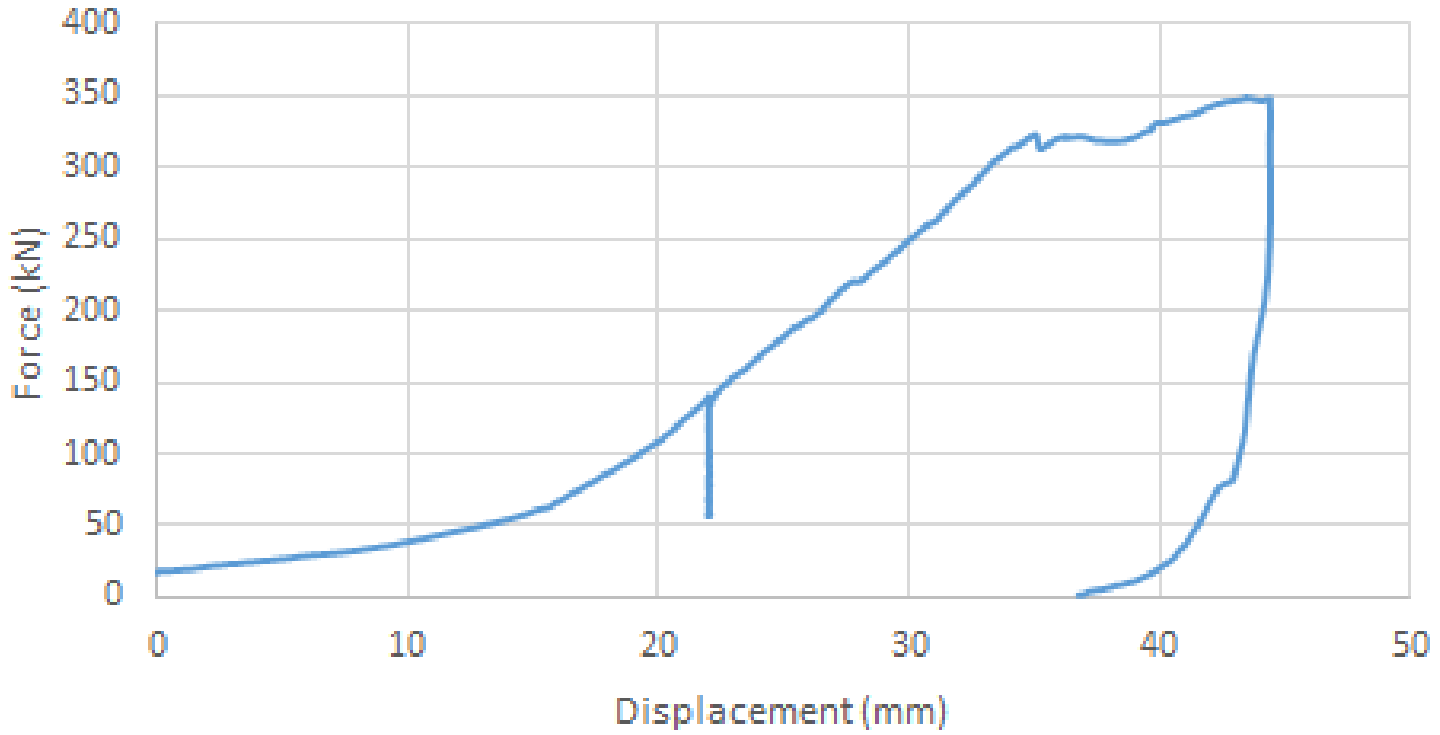


Experimental Tests

- **Test Setup of a SMART Shear Key**

EXPERIMENTAL TESTS

- **Load-Displacement Curve**



EXPERIMENTAL TESTS

- **Completion of the Shear Key Test at Preset Stroke Limit**

Experimental Tests

- **Final Condition of the SMART Shear Key**

Concluding Remarks

- **The SMART shear keys show a significant load capacity to accommodate the movement of bridge girders, satisfactory ductility and adaptability to reduce the pounding between the shear keys and girders.**
- **The Sliding stage makes the SMART shear key adaptable to the movement of bridge girders where the aggregate interlock or the friction between two modules dominates the resistant force.**
- **The Contact and Yield stages sustain the ability of the SMART shear key to restrain the movement of bridge girders, where the kinking and bending effects of steel bars dominate the resistant force.**

ACKNOWLEDGEMENT

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