# Analytical simulation on experimental seismic response of headed anchors embedded in reinforced concrete

**Seiji NAGATA**[*1], Toyofumi MATSUO[*1], Hironori MOROZUMI[*2] and Keizo OHTOMO[*1]

*1 Central Research Institute of Electric Power Industry

*2 Kansai Electric Power Company

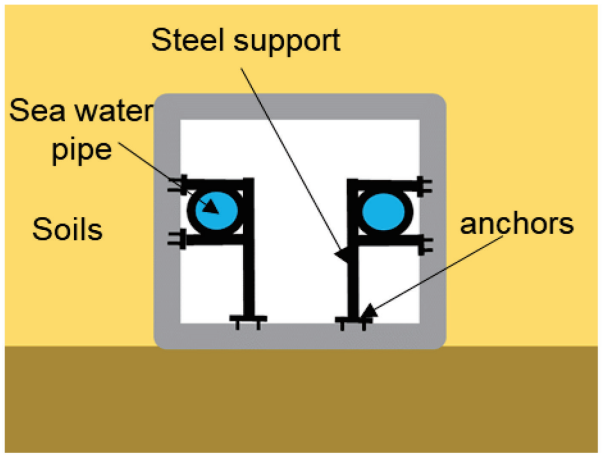
# Background and Objectives of This Research

## Background

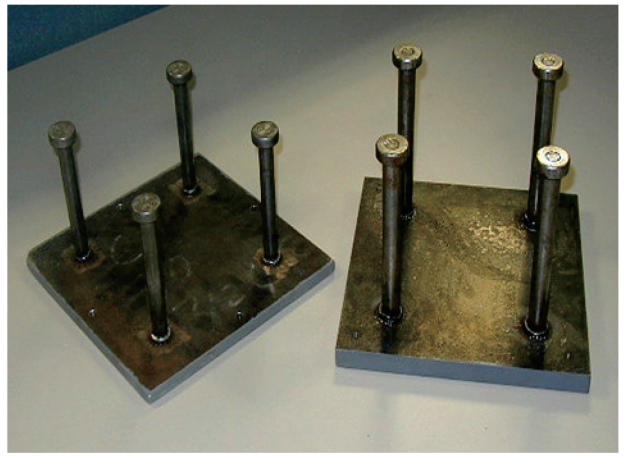
- In cooling facilities at electric power plants, equipment and piping are usually fastened to RC member using anchors.
- Current seismic design allows partial cracks of concrete unless they exceed ultimate state.
- Since structural resilience is much attributed to such connections, seismic behavior considering cracks of concrete should be carefully evaluated in earthquake prone countries.

## Objectives

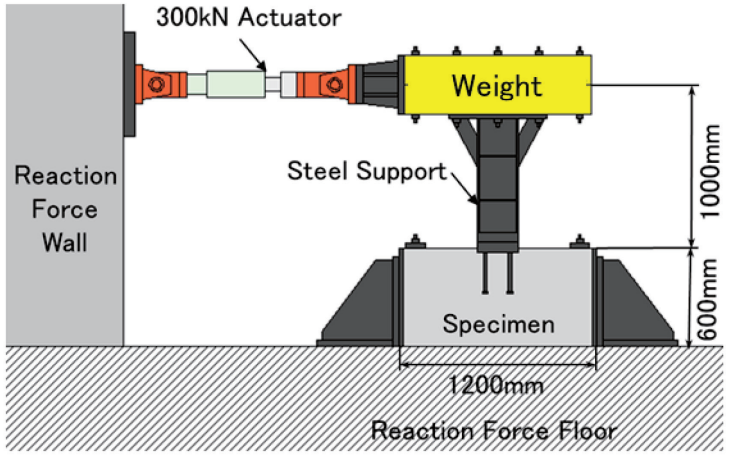
- Clarify nonlinear behavior of headed anchors based on static and dynamic tests, focusing on failure mode of anchors and presence of.
- Simulate experimental results using analytical model with translational and rotational springs.



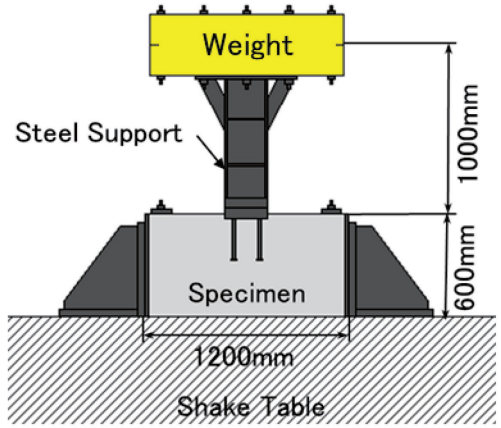

Piping system supported by anchors



Headed anchor bolts




Static test (cyclic loading test)




Dynamic test (hake table test)

# Experimental Performance of Headed Anchor Bolts

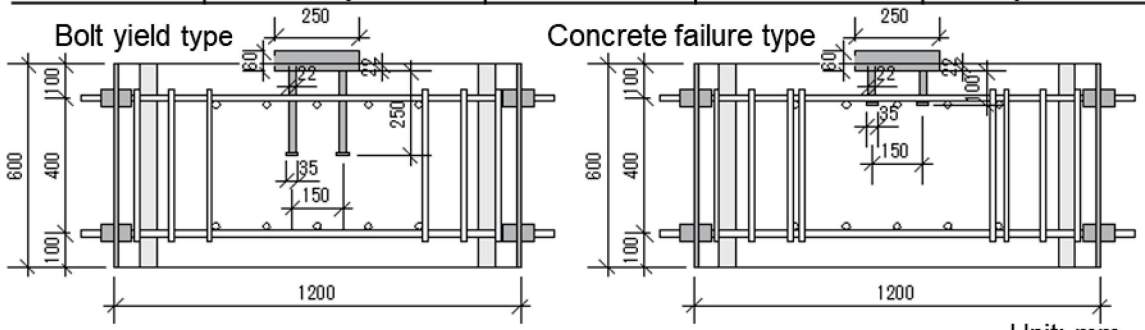
## Experimental condition

- Specimens are RC blocks with 4 headed anchors. Failure modes expected are steel bolt yield and concrete cone failure, associated with bolt length.
- Experimental methods for assessing hysteretic behavior of anchors are cyclic loading test (static test) and shake table test (dynamic test).

## Experimental performance

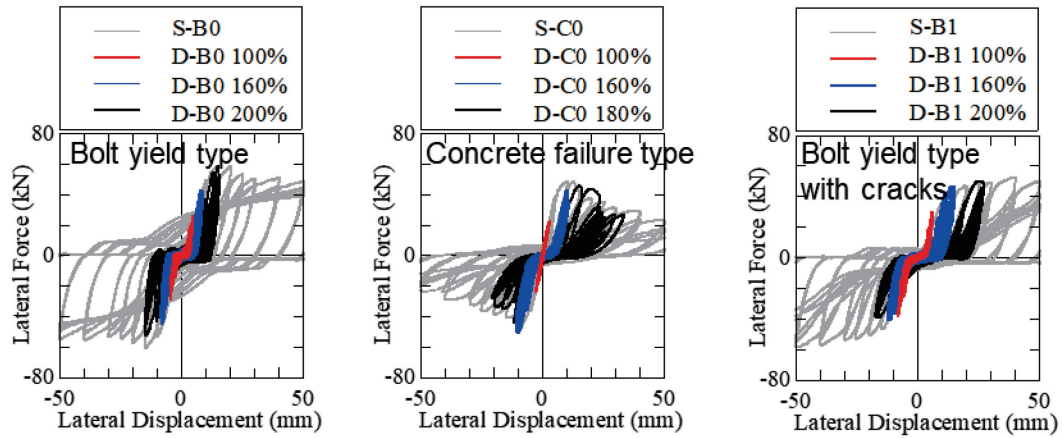
- Lateral strength in post-peak region exhibits more stable in bolt yield type than concrete failure type. In bolt yield type, effect of cracks is less significant.
- Force and displacement performance in static and dynamic tests correspond well, regardless of failure mode and presence of flexural cracks in concrete.

| Specimen | Failure mode | Bolt length | Initial cracks | Test methods |
|---|---|---|---|---|
| S-B0 | Bolt yield | 250mm | Without | Static |
| S-C0 | Concrete failure | 100mm | Without | Static |
| S-B1 | Bolt yield | 250mm | With | Static |
| D-B0 | Bolt yield | 250mm | Without | Dynamic |
| D-C0 | Concrete failure | 100mm | Without | Dynamic |
| D-B1 | Bolt yield | 250mm | With | Dynamic |




Test cases and test specimens

Unit: mm




Lateral force and displacement performance based on static and dynamic tests

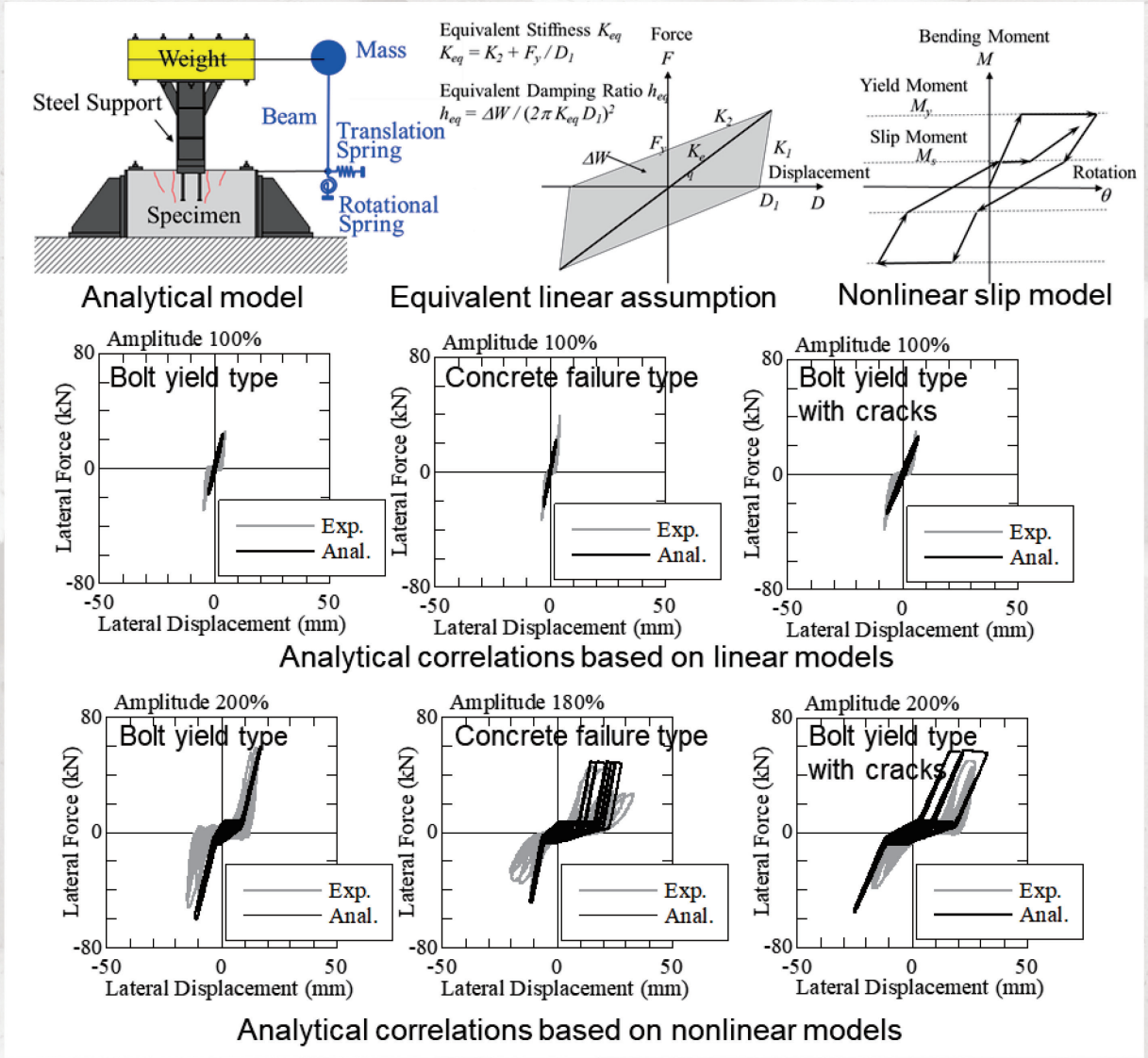
# Analytical Correlation for Experimental Results

## Analytical idealization

- Hysteretic behavior of anchors are modeled with translational and rotational spring system.
- In linear analysis, equivalent stiffness and damping ratio obtained by experiment are used.
- In nonlinear analysis, nonlinear slip model for moment and rotation relationship is applied.

## Analytical correlation

- Overall hysteretic behavior under dynamic loads are well simulated based on the analytical model.
- Insignificant nonlinear response allows to employ equivalent linear stiffness and damping ratio.
- Significant nonlinearity under relatively excessive seismic loads will require nonlinear hysteretic model to provide more narrow correlations.



# Thank you for your attention!

**Seiji NAGATA**

**n-seiji@criepi.denken.or.jp**

## Acknowledgement

This research is a part of the project research ‘Advanced Study on the Verification Method of Seismic Performance of Underground Reinforced Concrete Structures in Nuclear Power Plants’ which was jointly carried. The authors are grateful for the interest and advice by the above power companies, as well as to the members of the evaluation committee, which was organized by the Japan Society of Civil Engineers and chaired by Professor K. Maekawa of Yokohama National University.