Seismic Retrofit of Gusset Plate Connections through Finite Element Analysis

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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1. Objectives

INVESTIGATE THE BEHAVIOR OF A STEEL CONCENTRICALLY BRACED FRAME WITH FINITE ELEMENT MODELLING

- Study the behavior of the bracings connection and identify the cause of the observed damage
- Propose and evaluate retrofit solutions

2. Study Case

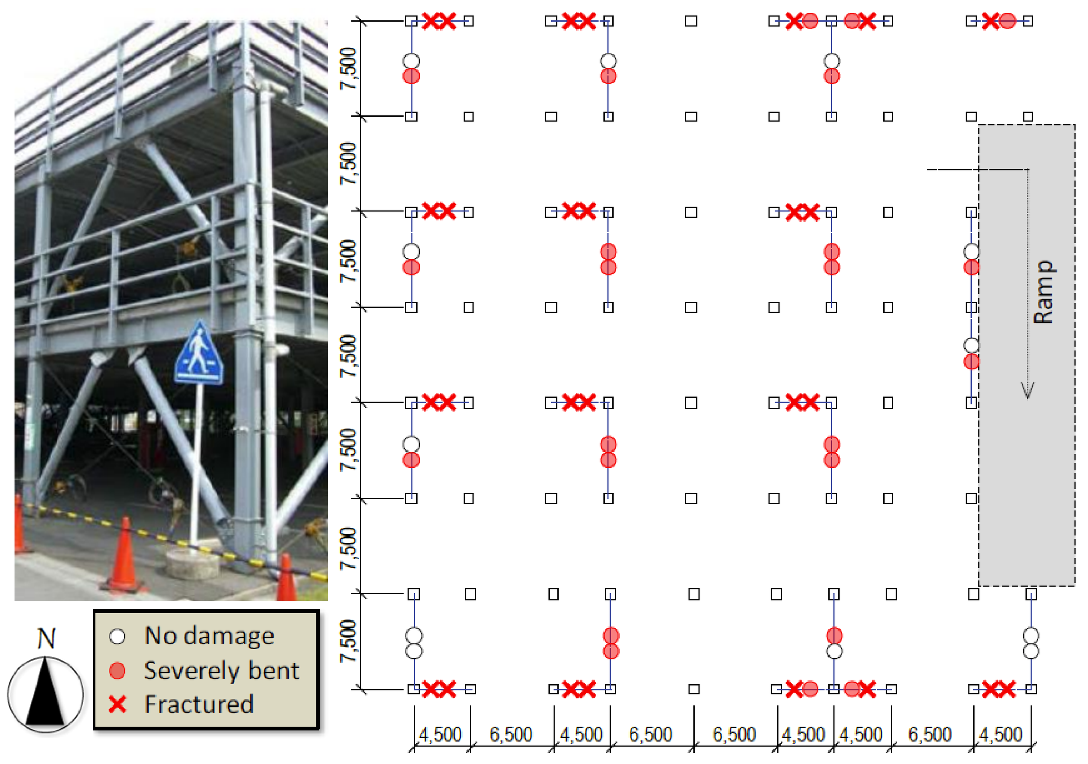

Fig 1. Damaged parking ramp and plan indicated damage location for the first story

- The structure is a two-story parking garage with concentrically braced frame as laterally-resisting system.
- After the 2011 Tohoku Earthquake in Japan, most of the braces in the east-west direction were fractured at the gusset plate while the remaining ones were severely bent.

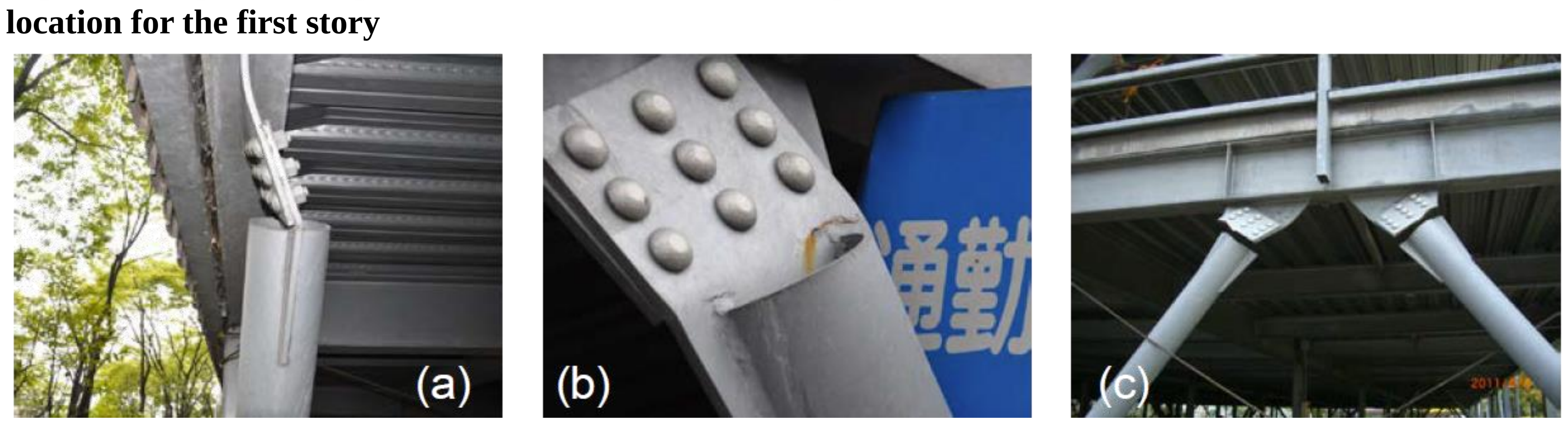

Fig 2. Connection damage: a) bent out of plane; b) fracture initiation; c) complete fracture

3. Numerical Model in Abaqus

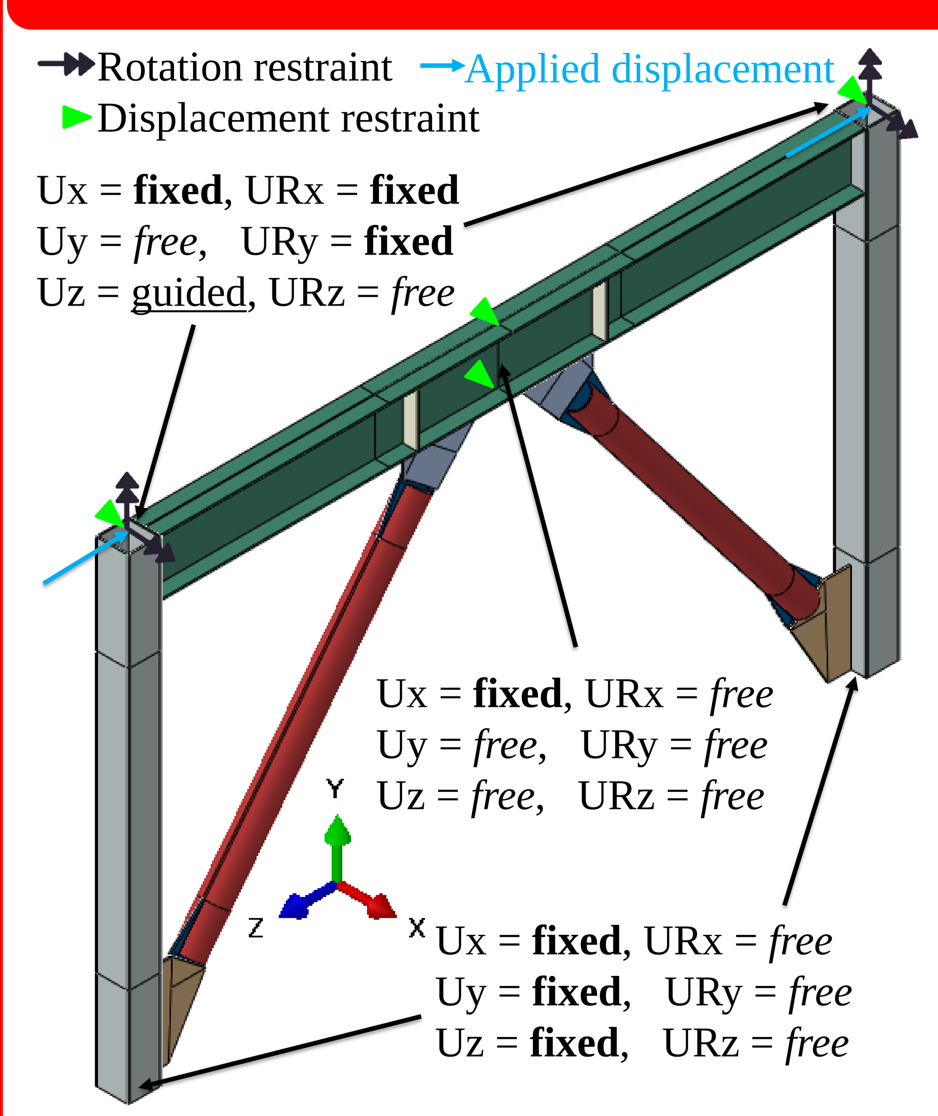

Fig 3. Boundary conditions in the numerical model

- Steel material: quad-linear law with isotropic hardening, S275 for the braces and S235 for all others members
- The beam is simply connected to the face of each column
- The rivets were not explicitly modelled to simplify the model
- Mesh element: C3D20R, second order hexahedron using reduced integration
- Mesh element size: 10-20 [mm]
- Two elements are used across the thickness of each member to capture local deformation and local buckling effect

4. Fracture Analysis

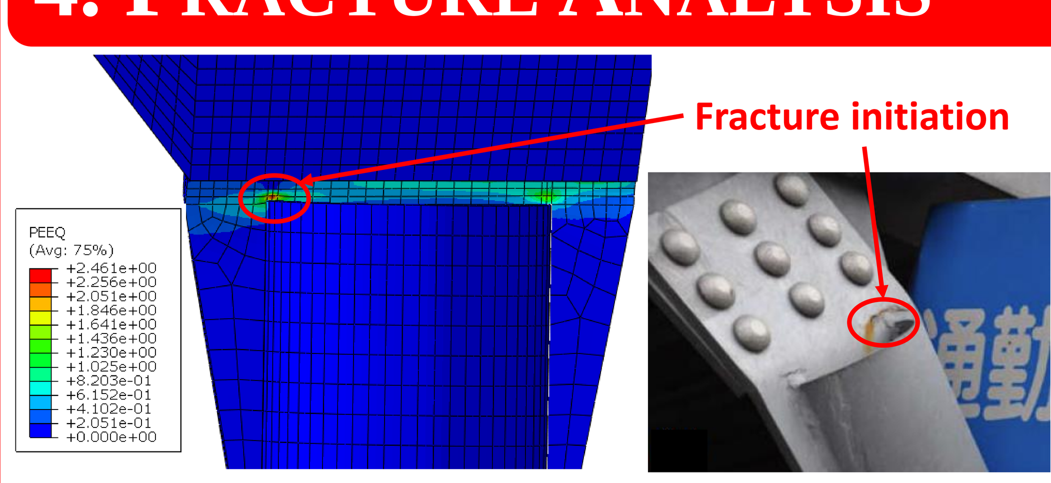

Fig 4. Location of the fracture initiation

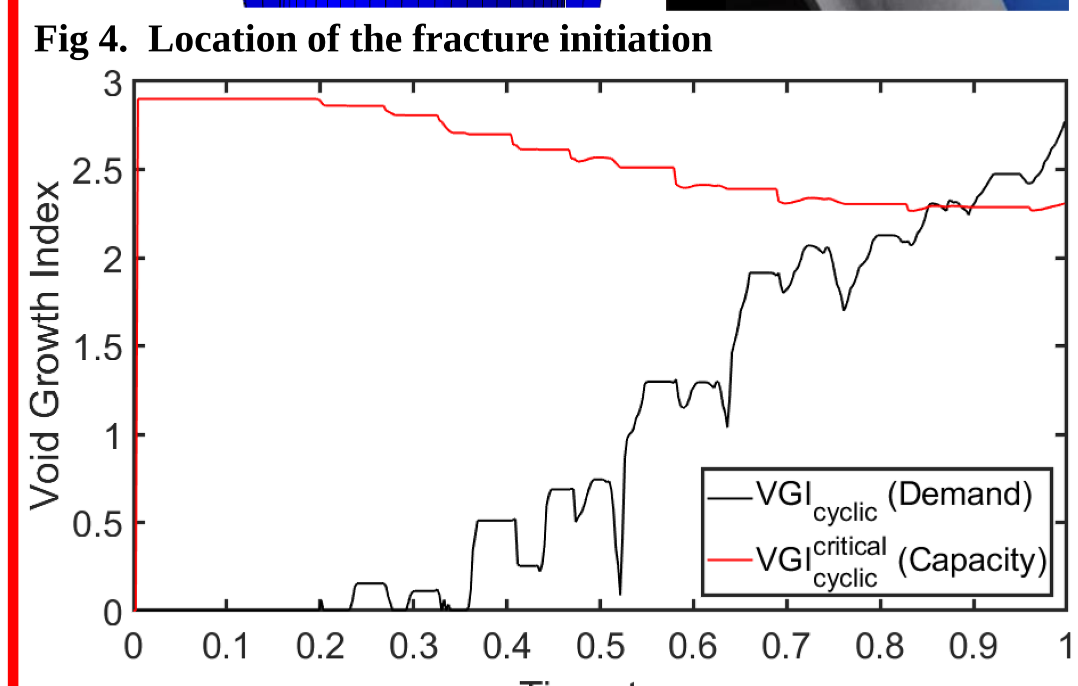

Fig 5. Void Growth Index

- Fracture analysis has been assessed with the Cyclic Void Growth Model (CVGM).
- The CVGM represents ductile fracture mechanism through plastic strain and stress triaxiality histories.
- The model states that fracture is supposed to occur when the Void Growth Index (VGI) exceeds a specific critical value treated as a material property.
- The analysis shows that fracture should occur at approximately 0.6% story drift ratio.

5. Retrofit Assessment

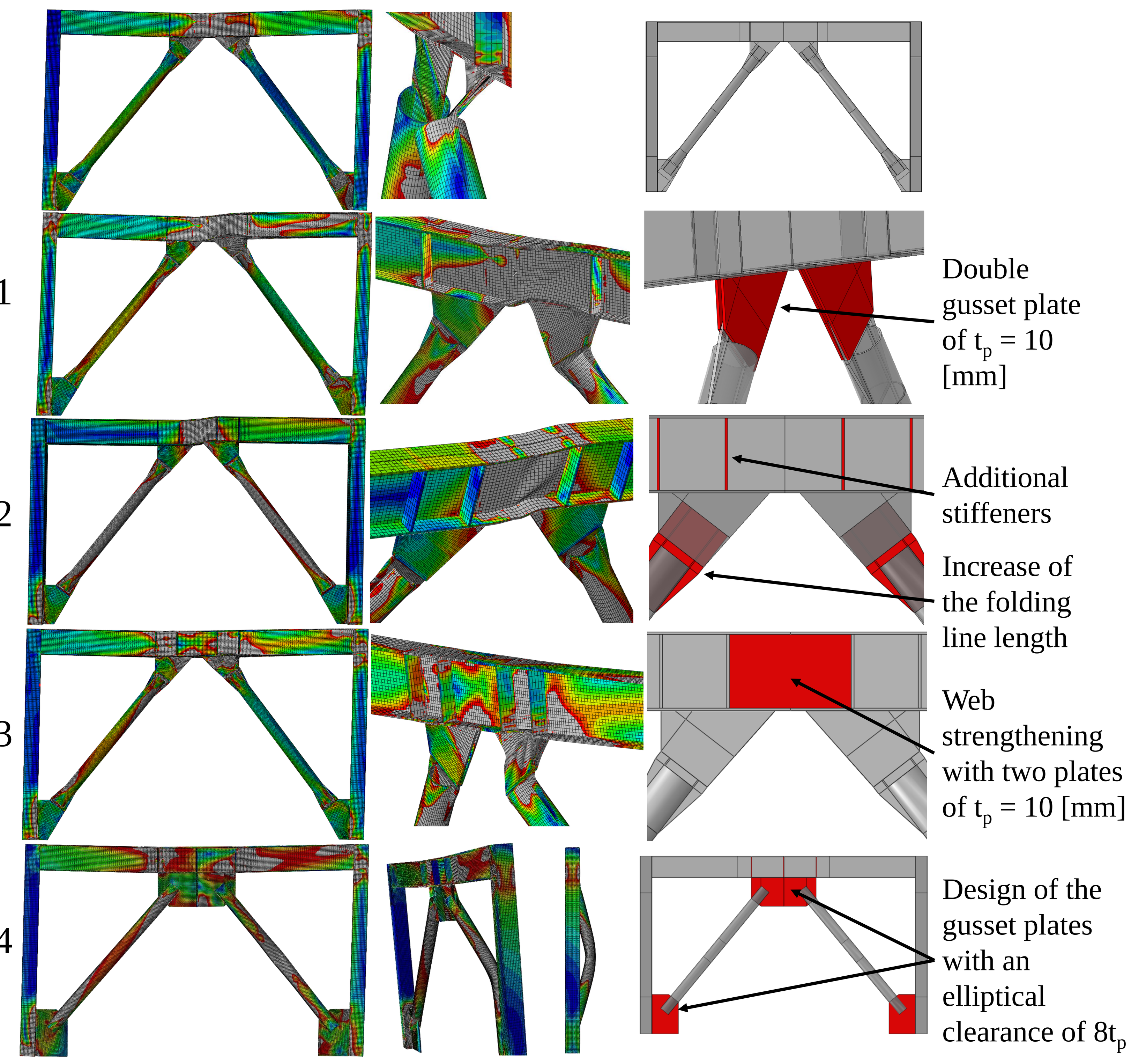

Fig 6. Failure mechanisms of original and retrofit structures and retrofitted parts drawn in red

Model	Failure mechanism	Story shear force at failure	Story drift ratio at failure
Original structure	Double hinging mechanism of the brace connections	325 [kN]	0.14%
Retrofit 1	Shear failure of the beam web followed by double hinging mechanism	825 [kN]	1.37%
Retrofit 2	Shear failure of the beam web followed by double hinging mechanism	884 [kN]	1.75%
Retrofit 3	Over-stiffened beam web and insufficient rotation capacity of the gusset plate led to double-hinging mechanism	869 [kN]	0.42%
Retrofit 4	Buckling of the brace in compression	946 [kN]	0.96%

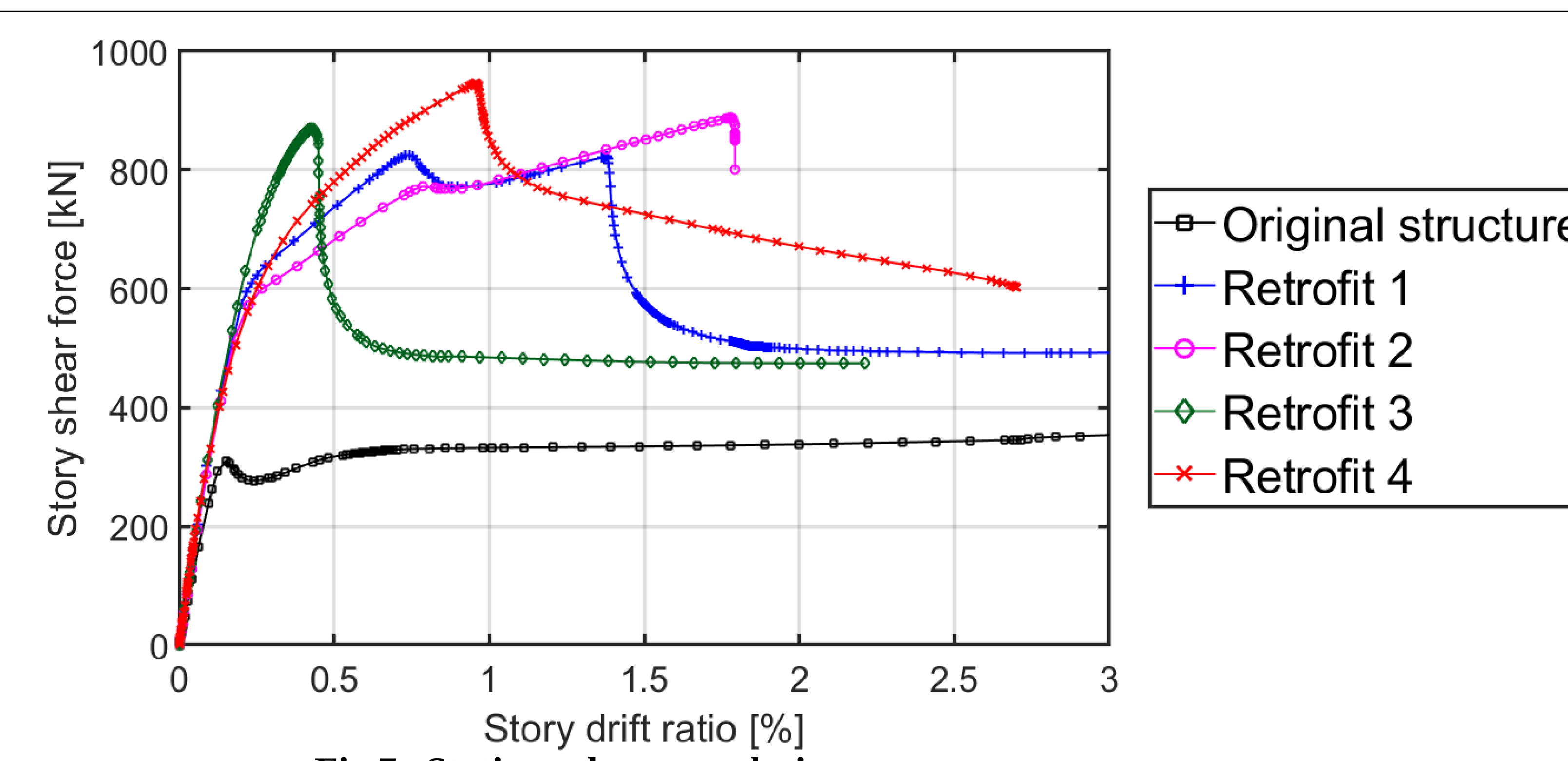

Fig 7. Static pushover analysis responses

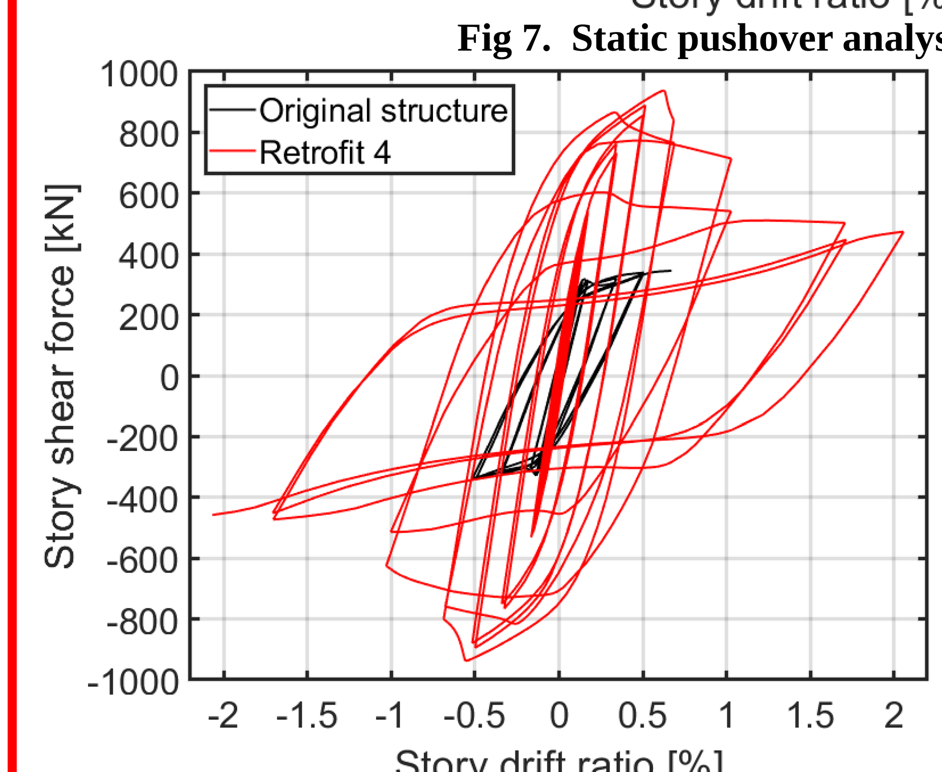

Fig 8. Cyclic Loading Response

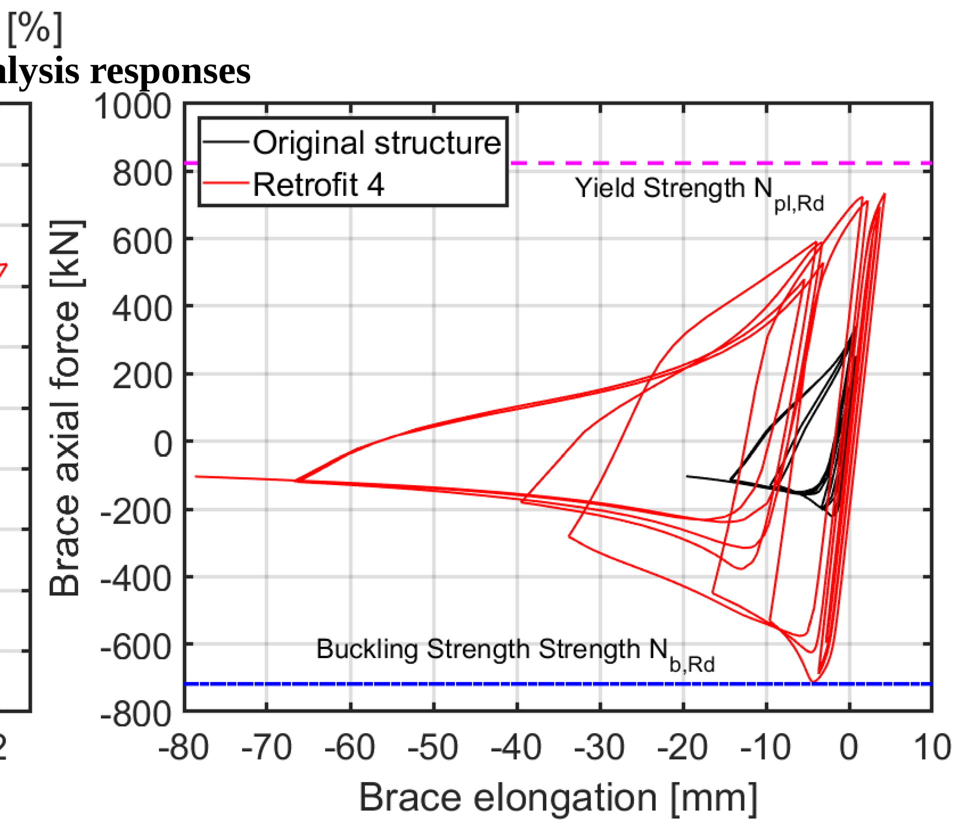

Fig 9. Hysteresis of brace

6. Conclusion

- The reason behind the failure is the concentration of inelastic deformation in the gusset plate forming a double hinging mechanism when the brace was in compression because of the eccentricity in the gusset plate connections.
- Several retrofit concepts have been simulated and each of them observed a considerable increase both in strength and in deformation ductility.
- Retrofit n°4 proved to be the best alternative as it presented superior pre- and post-failure behavior.