Seismic Performance Evaluation and Retrofit of Existing Steel Frame Buildings

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Nebua Ginette Siani

Academic year 2017-2018

Supervisor: Prof. Dr. Dimitrios G. Lignos; Advisor: Doctoral Assistant Hiroyuki Inamasu

Resilient Steel Structures Laboratory (RESSLab), Swiss Federal Institute of Technology, Lausanne (EPFL)

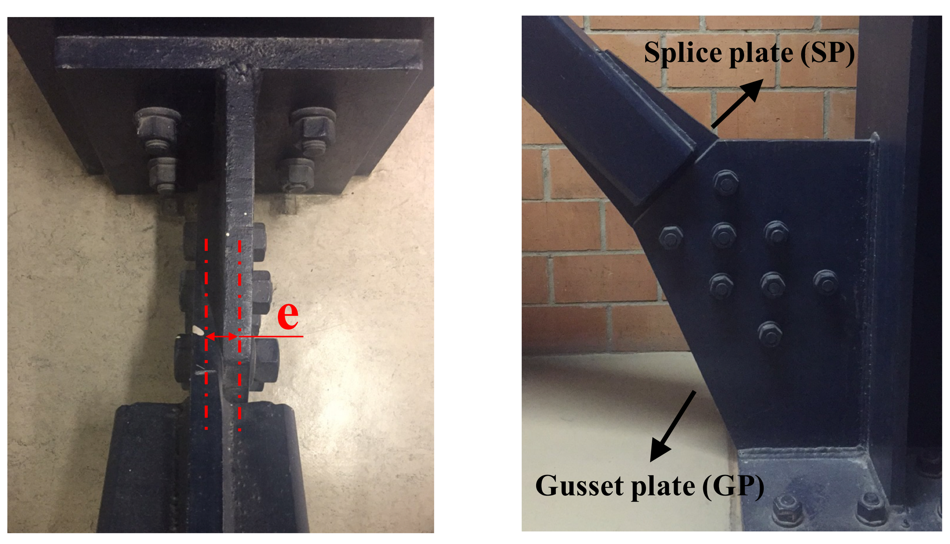
RESSLab Resilient Steel Structures Laboratory

1. Objectives

INVESTIGATE THE SEISMIC BEHAVIOUR OF AN EXISTING STEEL FRAME BUILDING LOCATED IN SWITZERLAND BASED ON RESPONSE HISTORY ANALYSIS

- Review existing building structural details
- Identify potential structural deficiencies through the development of nonlinear building models to simulate the behavior of steel CBF systems
- Assess the seismic performance of the steel building
- Propose and evaluate a retrofit solution

2. Target building



(a) Upper view (b) Lateral view

Fig 1. Gusset plate connection with single-sided splice member in GC building

EPFL CIVIL ENGINEERING BUILDING

Existing steel braced frame building that has been designed from the early 1970s utilizing a steel lateral load resisting system with practically no seismic design requirements ➡ Significant uncertainty regarding its seismic performance due to:

- Seismicity change: new specific spectrum with higher solicitations available in 2012 for EPFL site
- Loading eccentricity: gusset plate connections with single-sided splice members producing local out-of-plane eccentricity
- New modeling and analysis approach: nonlinear behavior of this building connections has never been tested using a concentrated plasticity approach

3. Critical CBFs

Name	General features
CBF1	3-story CBF Inverted V-bracings
CBF2	3-story CBF V-bracings
CBF3	4-story CBF V-bracings + RC wall in the top story

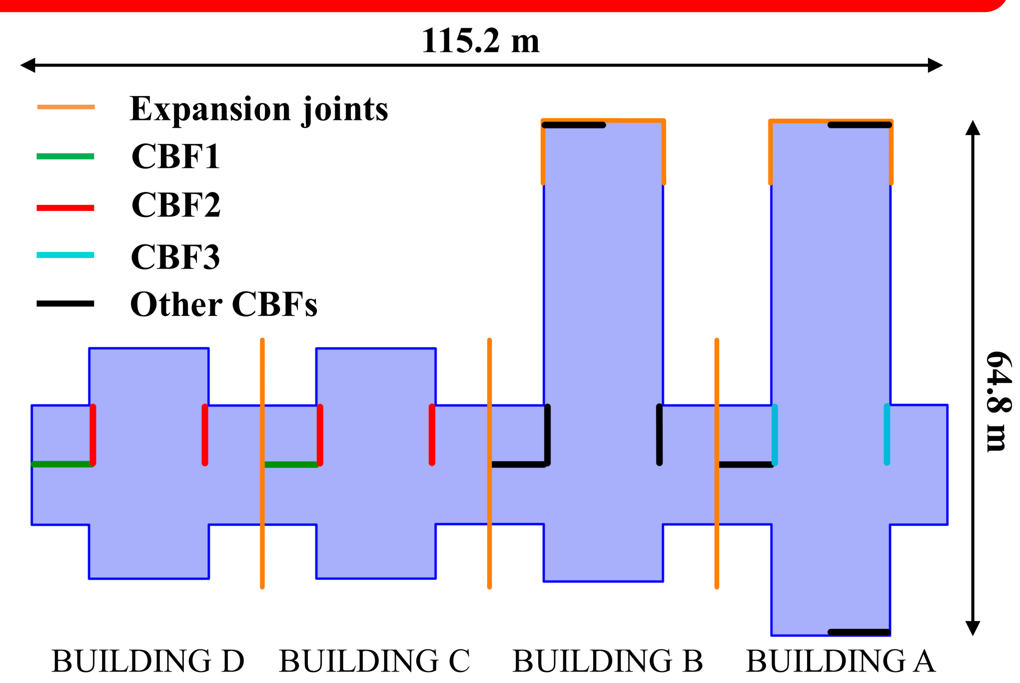


Fig 2. Plan view of GC building

4. Numerical model in OpenSees

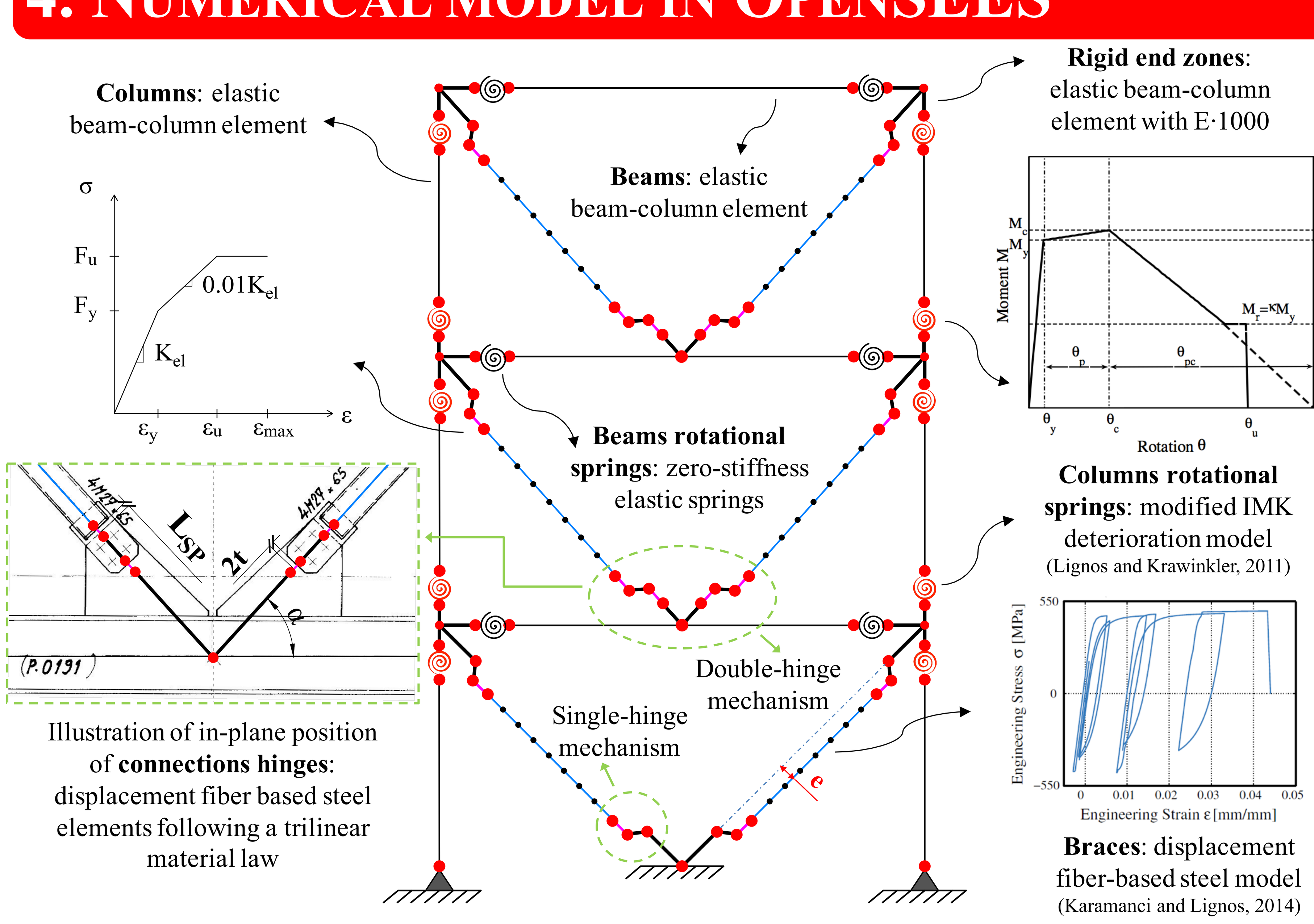


Fig 3. Example of model idealization - CBF2 (H_{tot} = 11.3m; W_{bay} = 7.2m)

5. Nonlinear response history analysis

5.1 Target Building Performance Levels

Tab. 1. Target building performance levels

Seismic hazard level	Performance level	Demand adjustment
50% / 50 years	Immediate Occupancy (IO)	x0.4
20% / 50 years	Life Safety (LS)	x1.0 (DLE)
2% / 50 years	Collapse Prevention (CP)	x1.5 (MCE)

According to ASCE-SEI-41-13 standard:

- **IO**: the structure remains safe to occupy and retains its preearthquake strength and stiffness
- **LS**: the structure has damaged components but retains a margin against the onset of partial or total collapse
- **CP**: the structure has damaged components and continues to support gravity loads but retains no margin against collapse

5.2 Results

Tab. 2. Nonlinear response history analyses outcomes

Strutural Performance Levels	Immediate Occupancy	Life Safety	Collapse Prevention
Check Type	Global check		
Illustrative Damage (Table C2-4 of ASCE-SEI-41-13)	Transient drift that causes minor or no nonstructural damage.	Transient drift sufficient to cause nonstructural damage.	Transient drift sufficient to cause extensive nonstructural damage.
Outcomes for the three seismic-force-resisting systems	Both the limit of 3% for the average peak SDRs and the limit of 4.5% for each SDR are respected.	Both the limit of 3% for the average peak SDRs and the limit of 4.5% for each SDR are respected.	Even if the limits are all respected, **the peak SDR of the first story of CBF3 goes beyond 3% for GM1.**
Check Type	Local check		
Illustrative Damage (Table C2-4 of ASCE-SEI-41-13)	Minor yielding or buckling of braces.	Many braces yield or buckle but do not totally fail. Many connections might fail.	Extensive yielding and buckling of braces. Many braces and their connections might fail.
Outcomes for the three seismic-force-resisting systems	**The limits for braces ultimate axial displacement are not respected. Some connections failure is observed.**	Each brace's ultimate average axial displacement respects its acceptamce criterion. **In CBF2 and CBF3, many connections totally fracture even if brace buckling does not occur.**	Each brace's ultimate average axial displacement respects its acceptamce criterion. **In CBF2 and CBF3, many connections totally fracture even if brace buckling does not occur.**
Check Type	Additional considerations in line with building life cycle		
Illustrative Damage (Table C2-4 of ASCE-SEI-41-13)	Negligible permanent drift.	Noticeable permanent drift.	Extensive permanent drift.
Outcomes for the three seismic-force-resisting systems	The limit of 0.3% for each residual SDR is respected.	The limit of 0.3% for each residual SDR is respected.	Even if the limit of 0.3% is respected by the average residual SDRs, **the residual SDR of first story of CBF1 is about 0.55% for GM1.**

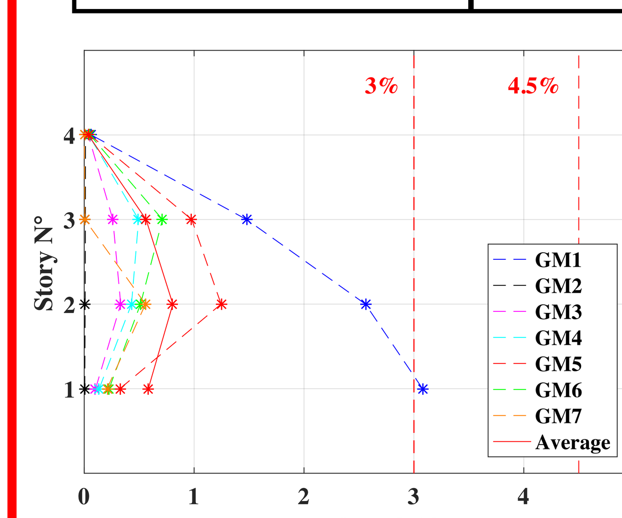


Fig 4. Peak SDRs (CP) - CBF3

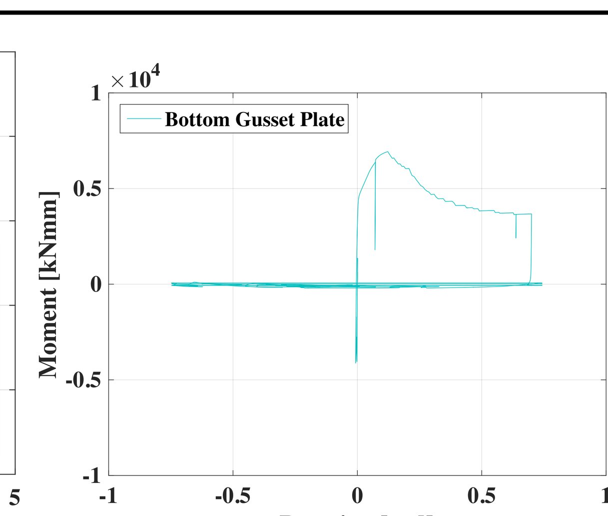


Fig 5. GP failure (CP) - CBF2

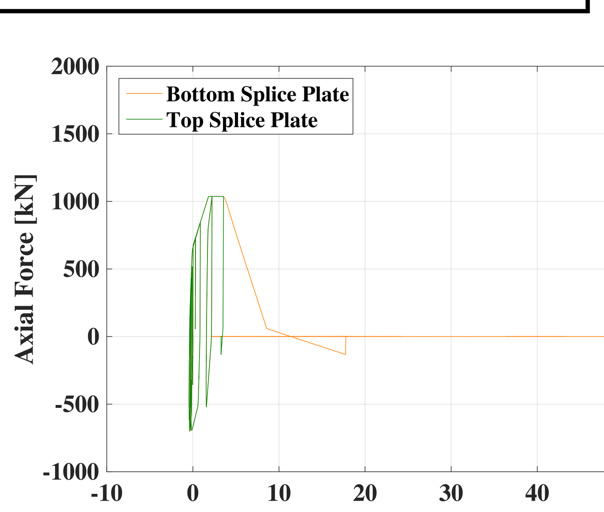


Fig 6. SP failure (CP) - CBF3

6. Retrofit solution

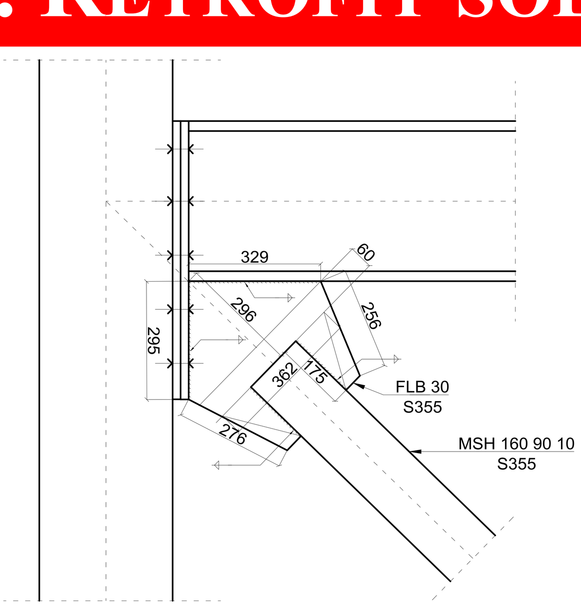


Fig 7. Retrofitted GP connection

Local modification of all the GP connections:

Seismic design for a ductile performance

- Removal of the out-of-plane eccentricity
- Incorporation of a clearance distance of 2t
- Respect of hierarchical order of yielding in elements

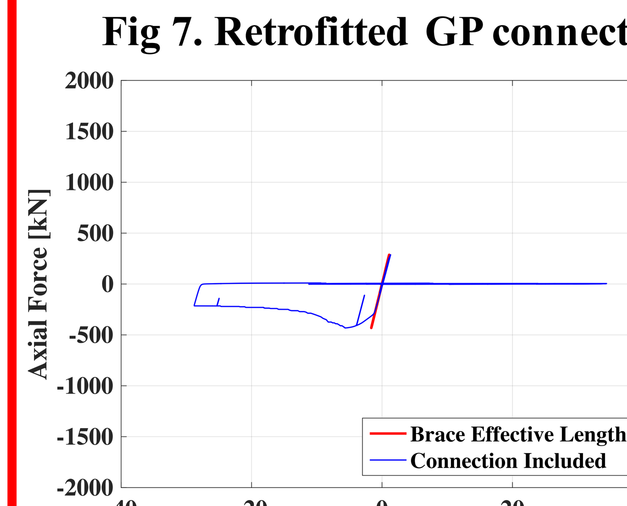


Fig 8. Original CBF2 response

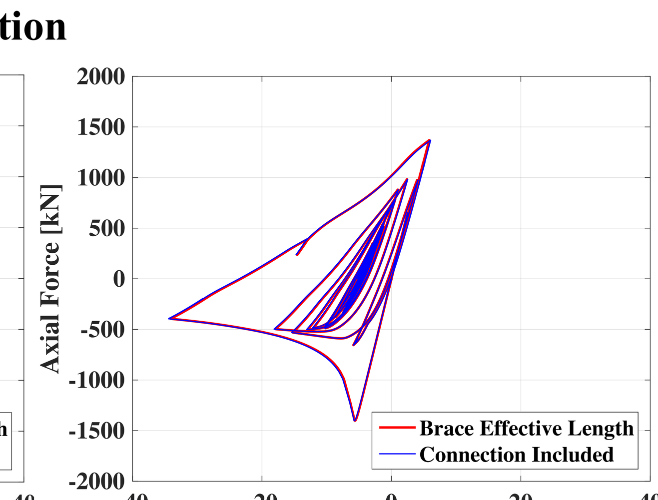


Fig 9. Retrofitted CBF2 response

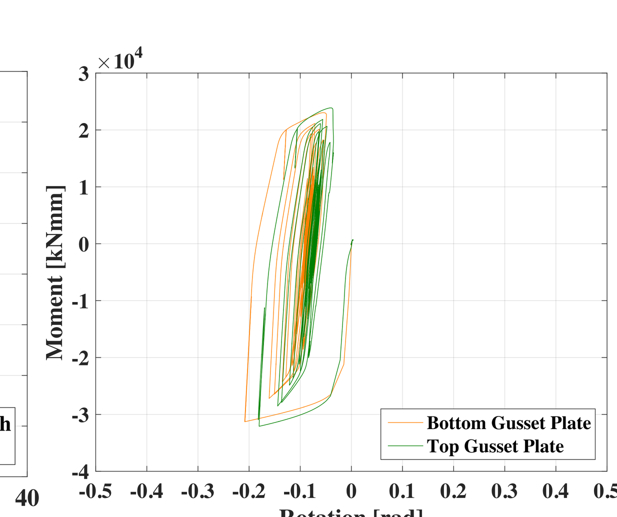


Fig 10. Retrofitted GP response