Japanese Lessons on RC building collapse and importance of beam-column joint

H. Shiohara, PhD. FACI

Professor
Graduate School of Engineering
Department of Architectural Engineering
The University of Tokyo
Tokyo, Japan 113-8656
shiohara@arch.t.u-tokyo.ac.jp

Japanese Past Earthquakes and Countermeasures

1968 1971 1978 1981 1995 2000 2011 2017

1968 Tokachi-Oki Earthquake M7.9

1971 Revision of BSL Enforcement Order

Amendment of RC Shear design provisions

1978 Miyagi-Oki Earhtuqkae M7.4

1981 Revision of BSL Enforcement Order

Introduction of Lateral Capacity Calculation

1995 Kobe Earthquake M7.3

Near fault earthquake・Confirmation of the effectiveness of Lateral Capacity Calculation introduced in 1981

1995 Seismic Retrofit Promotion Act

2005 E-Defense Facility, Miki, Kobe

gen. I ～ 1971

gen. II ～ 1981

gen. III 1981 ～

2011 Tohoku-Taiheyo Earthquake M9.0

2013 Revision of Seismic Retrofit Promotion Act

Collapse of Buildings due to Beam-column joints

- ERROR of empirically revised seismic design provisions for RC beam-column joints

Design of confinement in RC members

Difference in the background of past earthquake damage makes a minor difference in seismic provisions in two countries

- Japan (AIJ)
  - Shear design has been emphasized for beams and columns
    - provisions for shear determine the hoop and stirrup

- US (ACI318)
  - Seismic detailing of transverse reinforcement has been emphasized for confinement

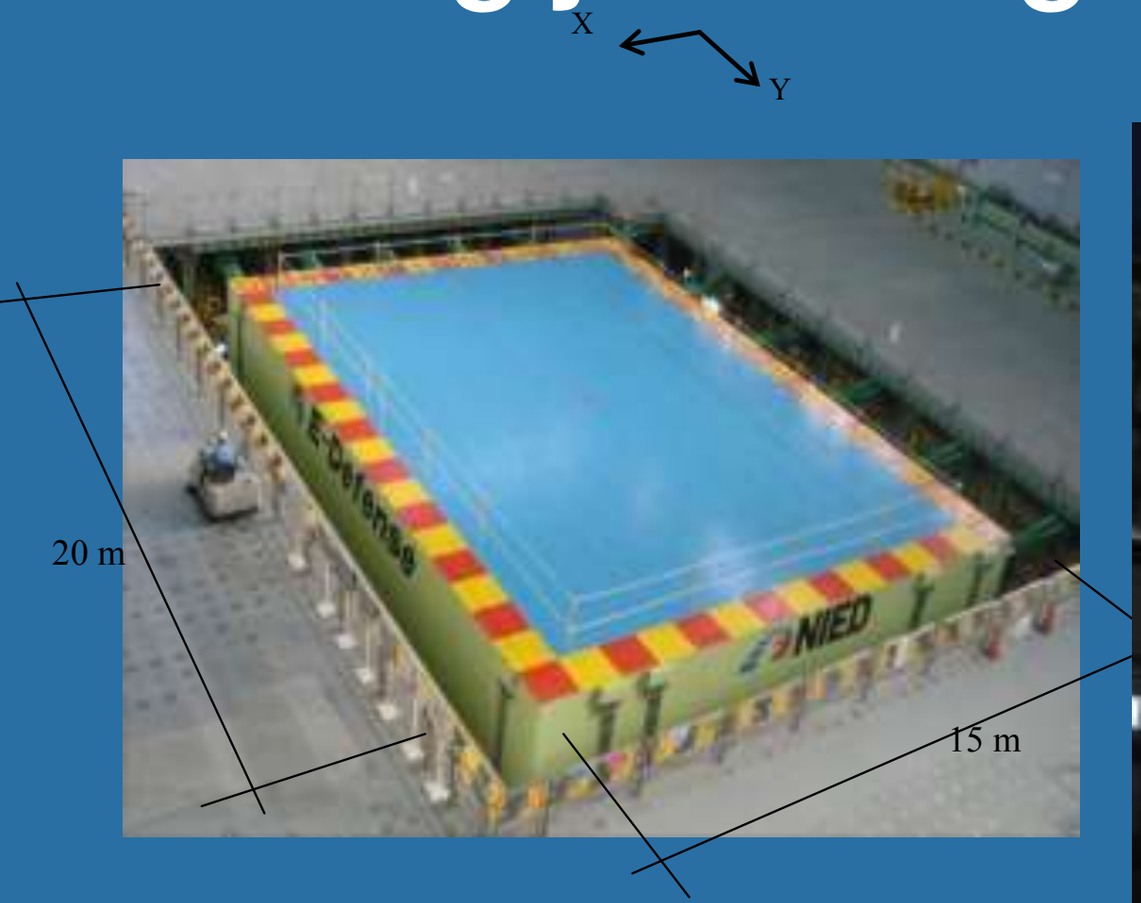
Design of beam-column joint

In 1980's, test data suggested the joint shear strength of beam-column joint is not be the function of joint hoops
(Japan-US-NZ trilateral coordinated research)

Different message to engineer

- Japan (AIJ)
  - Large column is necessary
  - Minimum joint hoop ratio is 0.2% for joint shear
  - No confinement requirement
- US (ACI318)
  - Joint hoops for confinement does not allow reducing the dimension of the column section
  - Beam-column joint needs to have joint hoop ratio as much as 1.0% because is it a part of column

Proving joint hinging by shaking table test



E-Defense 3D Shaking Table

National Research Institute for Earth Science and Disaster Prevention
Miki, Hyogo Prefecture, Japan

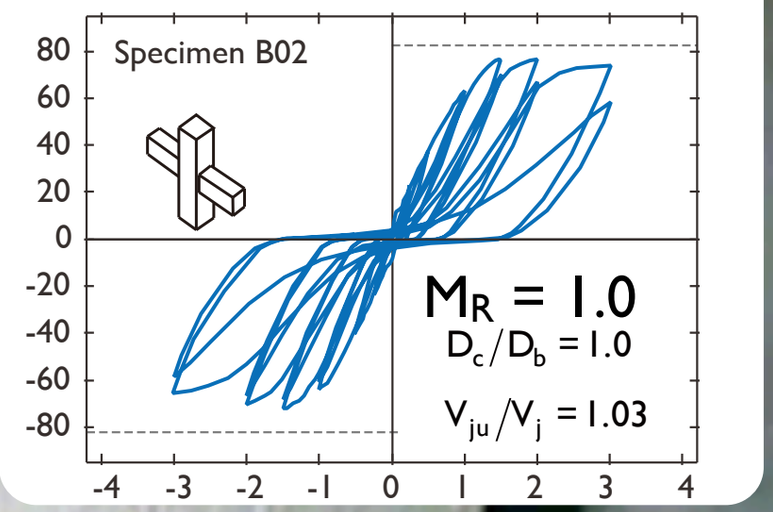
Nagae et al. (2015) Design Implications of a Large-Scale Shaking Table Test on a Four Story Reinfored Concrete Building, ACI Structural Journal, Vol. 12, No. 2, March 2015, pp. 135-146.

E-Defense

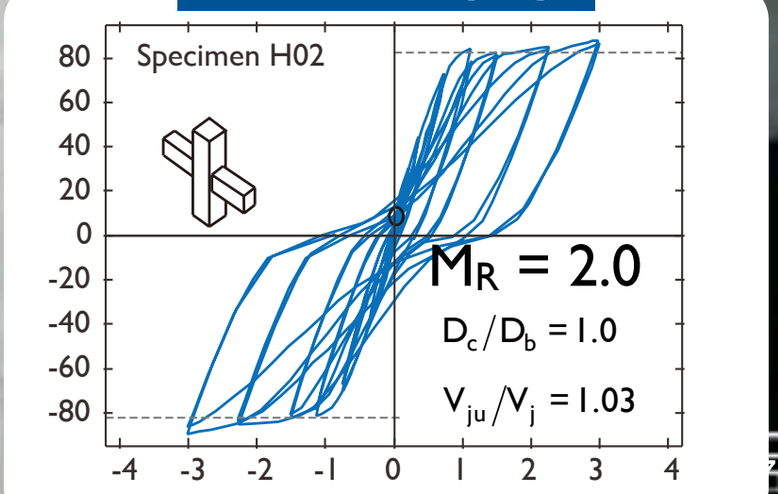
This test confirmed joint hinging at JMA Kobe 100%

Beam-column joint conformed to Japanese seismic provisions

Joint Hinging

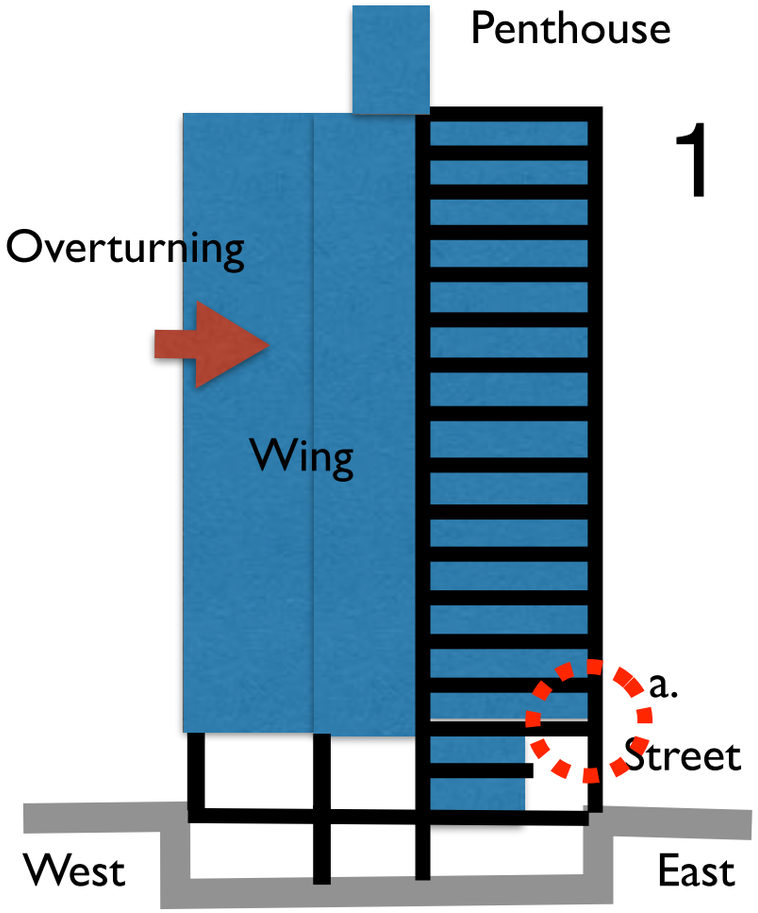


Beam Hinging



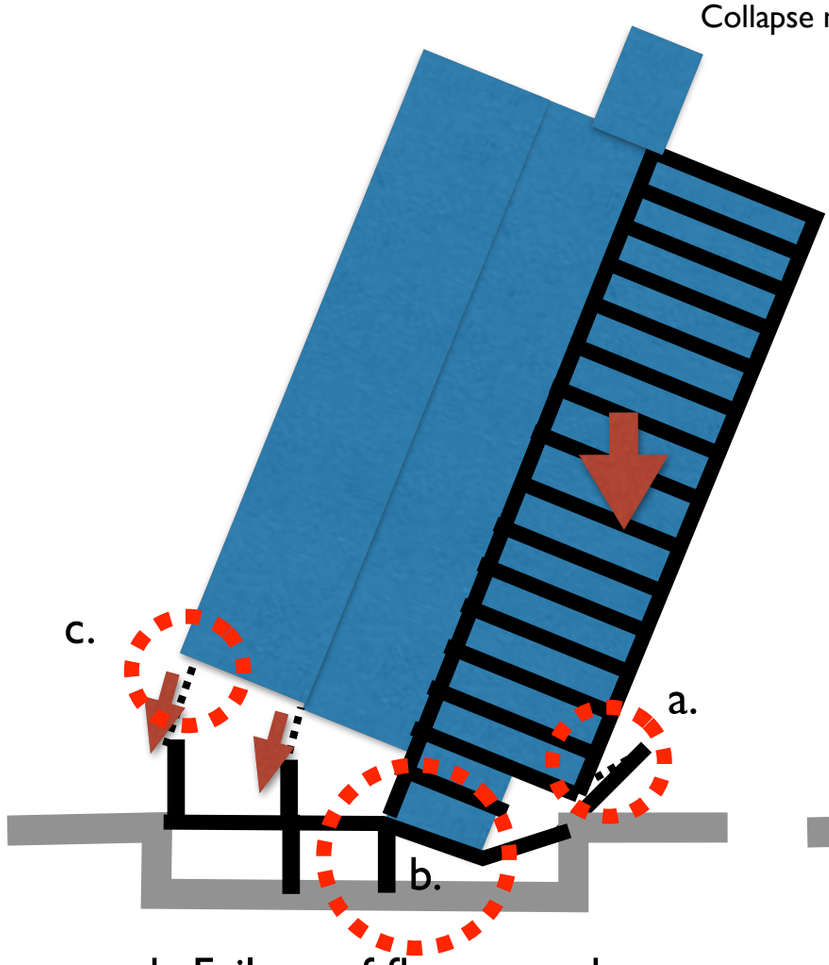
Recent earthquakes and building collapse

Collapse mechanism of the RC16story building by Hitoshi Shiohara 2016.2.25



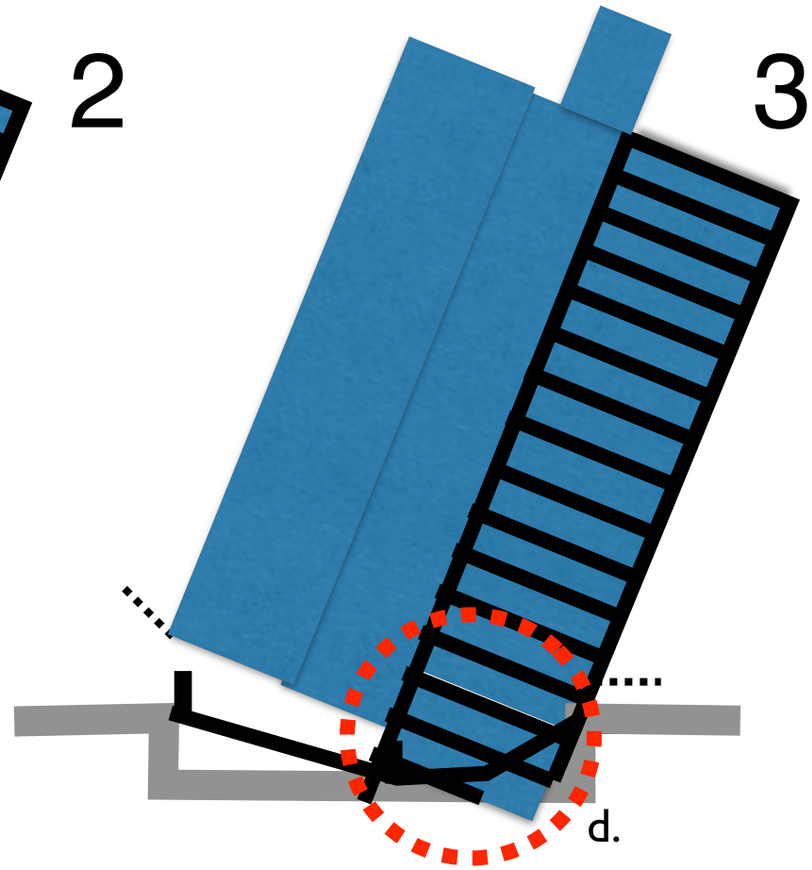
Basement (parking)

a. Failure of beam-column joints

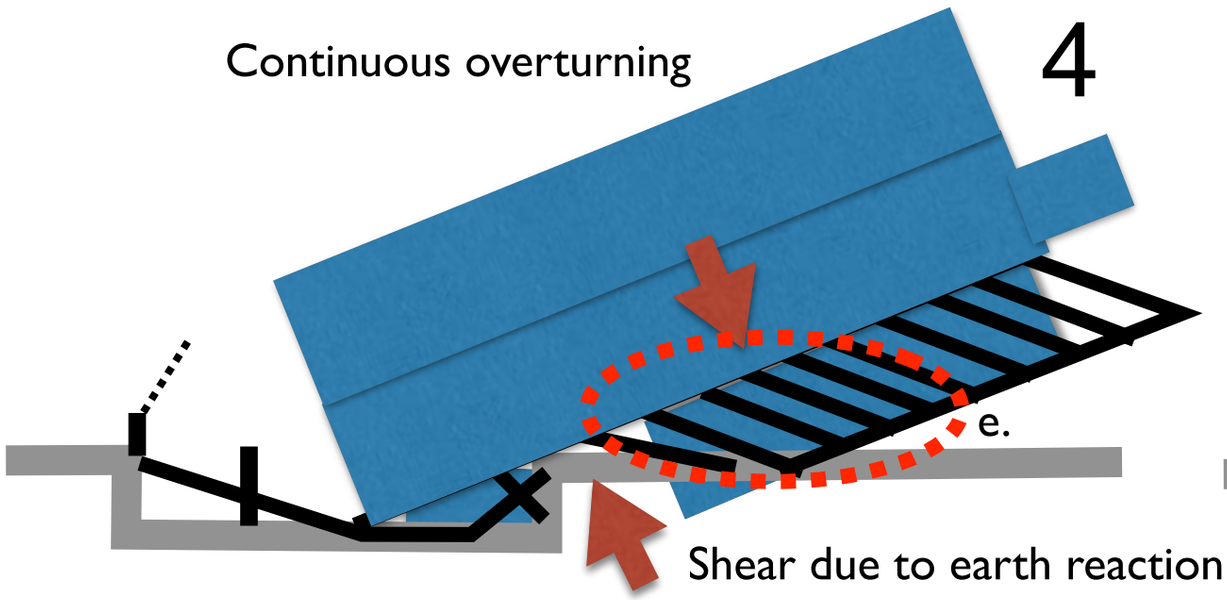


b. Failure of floor members

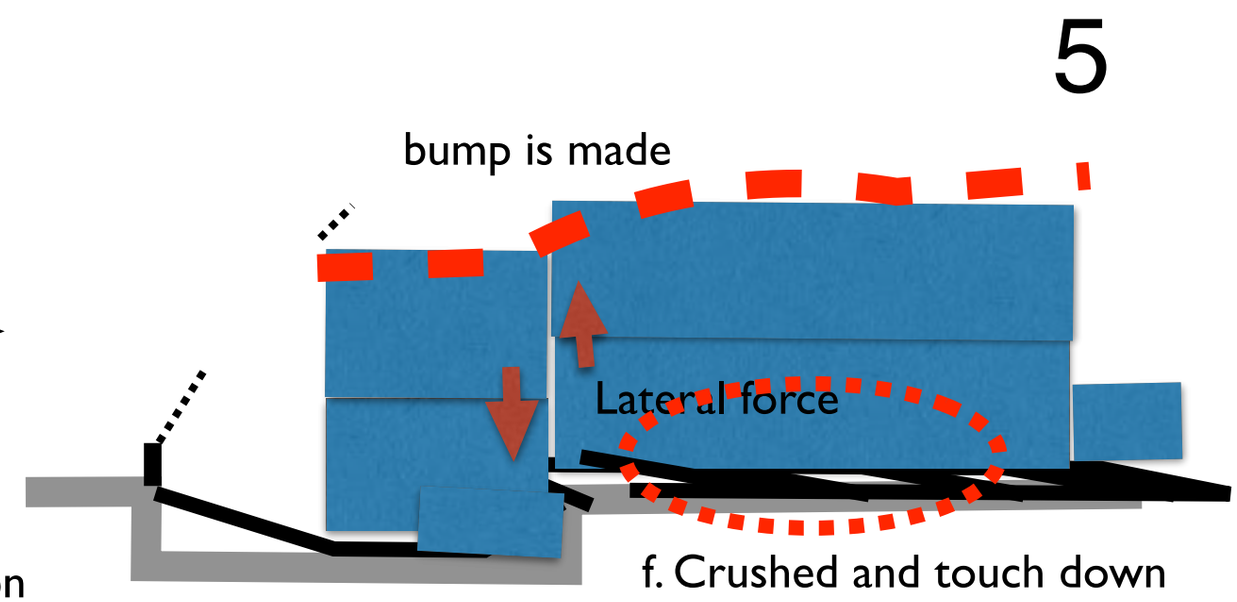
c. Fracture of column at lap splice joint



d. Sinking down due to gravity



e. Infill brick fall into pieces

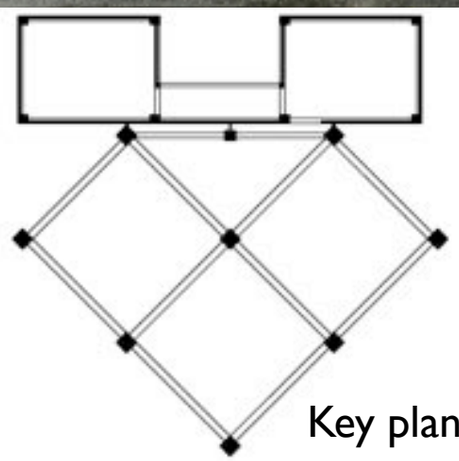


f. Crushed and touch down

Recent earthquakes and building collapse

Kumamoto 2016

After removal of architectural mullion



Key plan

Uto Municipal Building collapsed by 2016 Kumamoto earthquake, Kumamoto, Japan, built in the 1970's, but probably satisfied the current seismic provisions for beam-column joint of Japan. Detailed investigation is underway.

Beam-column Joint & Collapse of Buildings

Key plan

- The reinforcing detailing provisions for seismic design of RC beam-column joints is crucial for seismic performance of moment resisting frame structure.
- Careful selection of “test specimen,” “boundary condition” and “interpretation of statistical data” is necessary.
- Well designed 3D full scale shaking table tests provides most valuable lessons for such purpose.

Thanks
for your attention