A preliminary report about structural damages to RC/PC buildings in Kumamoto Earthquake

On April 14th, 2016 at 9:26 pm local time, a strong earthquake of Japan Meteorological Agency (JMA) magnitude 6.5 occurred in the Kumamoto area of Kyushu, west Japan. This was followed by the second one two days later on April 16th, 2016 at 1:25 am of JMA magnitude 7.3. A general description of the extensive damage to building structures has been reported by the local people, news agencies, and building safety inspection teams dispatched to the earthquake-stricken areas.

In order to investigate the extent of damage to reinforced and/or prestressed concrete buildings located in the affected areas, a reconnaissance team from the Kyoto University reinforced and/or prestressed concrete structure research laboratory was dispatched to Kumamoto. This document is an initial brief report from the 2-day field survey. The exact locations and the names of inspected buildings are not included. Moreover, almost all the information described is based on inspections from outside of the buildings. Further detailed damage inspection requires permission from either the property owners or city authorities.

Our special gratitude goes to the local people and authorities who, despite facing hardships, supported the reconnaissance team well.

Key reconnaissance facts:

Inspection days: 14th and 15th of May 2016
Inspected areas: Kumamoto city, Kikuyo town, Kashima town, Uto city, and Uki city
Target structures:
- ❖ Prestressed concrete buildings
- ❖ Retrofitted RC buildings
- ❖ Apartment houses with damaged non-structural RC walls
- ❖ Random buildings with severe damage

Reconnaissance team members:
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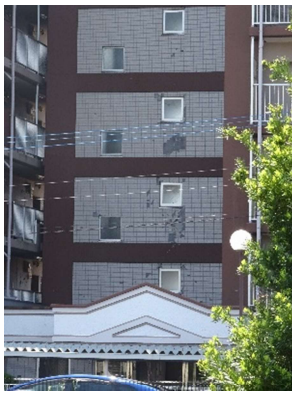
This English version was prepared with the help of Professor Gregory A. MacRae of the University of Canterbury, New Zealand.

[Apartment]
Building: Apartment A
Location: Kumamoto city, eastern district
Structural specifications: 10-story RC building (built in 1992) with north and south wings separated with expansion joints either side of the staircase block. The first story was open or *pilotis*, and used as parking lot space.
Damage: Even though the building was judged as "unsafe" for reoccupation, some families were living in their houses. In the south wing, severe damage to the shear wall of the first floor was observed. Concrete spalling at the base of the boundary column was significant. Several cracks were noticeable in the shear wall of the upper stories as well. In the longitudinal direction of this wing, failure of the shear wall as well as buckling of the longitudinal rebar of one column was significant. The out-of-plane shear cracks observed in the column were consistent with the occurance of out-of-plane shear cracks in the shear wall. In the north wing, shear cracks in the columns and wing walls were clearly seen from a distance.

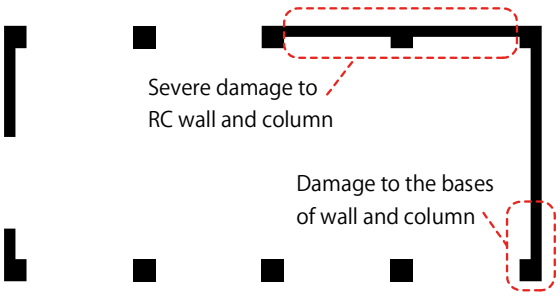
East side view

Visible cracks in walls (south wing)



Observed damage in non-structural walls (staircase block)

Spalling of tiles and concrete cover from wall (south wing)



Approximate plan of 1st floor of south wing

Damage to wall and column in longitudinal direction (1st floor of south wing)

Damage to column and wing wall (1st floor of north wing)

Building: Apartment B
Location: Kumamoto city, eastern district
Structural specifications: 5-story RC boxed wall building, built in 1982.
Damage: Spalling of mortar finishings at the wall base of the first floor was observed. Large cracks in the retaining walls were seen.

Spalling of finishing at wall base

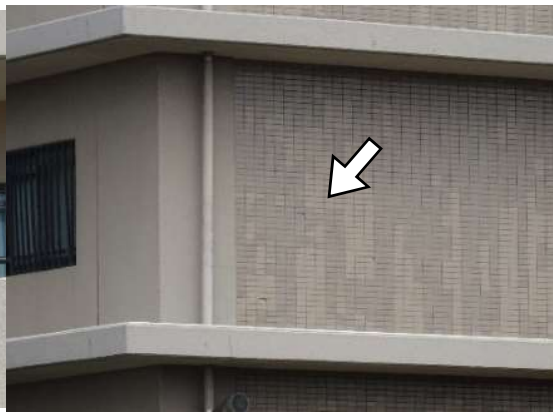
Crack at retaining wall

Building: Apartment C
Location: Kumamoto city, eastern district
Structural specifications: 11-story SRC (Steel Reinforced Concrete) building with penthouse, built in 1993
Damage: Concrete cracking and spalling were observed in non-structural walls of all the floors. No crack was seen in the walls of balconies. In the short span direction, or wall direction, some flexural-shear cracks in the shear walls were noticeable.

North side view

Damage in non-structural RC walls

Damage in non-structural RC walls



Flexural-shear cracks in shear wall

Building: Apartment D
Location: Kumamoto city, west district
Structural specifications: 9-story RC building, built in 1974
Damage: The columns of the open first story collapsed.

South side view

Column failed in the 1st floor

Building: Apartment E
Location: Kumamoto city, west district
Structural specifications: 5-story RC building
Damage: Damage was seen in the short columns of the first floor.

South-west side view

Damage in the short column

Building: Apartment F
Location: Kumamoto city, central district
Structural specifications: 6-story RC building with 3 bays in the east-west direction and 2 bays in the orthogonal direction, built in 1994.
Damage: Shear cracks in the non-structural RC walls and shear walls of the first floor were observed. The hanging walls of the 3rd floor on the south side experienced concrete crushing.

North-west side view

Wall cracks in the 1st floor

Diagonal cracks in non structural walls of the south side

Concrete crushing in hanging wall on the 3rd floor

Building: Apartment G
Location: Kumamoto city, central district
Structural specifications: 10-story SRC building built on *pilotis* with in 1985.
Damage: Diagonal cracks in non-structural walls were observed up to the 7th floor .


North side view


Diagonal cracks in non-structural wall

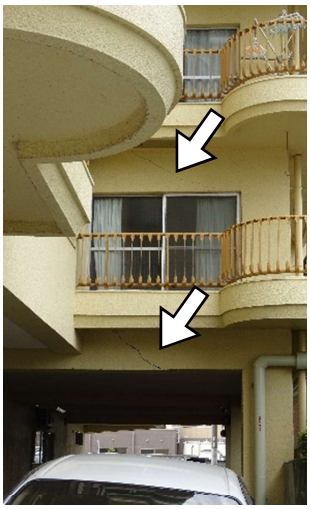
Building: Apartment H
Location: Kumamoto city, central district
Structural specification: 11-story SRC building
Damage: The non-structural walls on the lower floors cracked in shear, and some shear cracks extended into the adjacent columns.


West side view


Shear cracks in column

Building: Apartment I
Location: Kumamoto city, central district
Structural specification: 8-story RC building, built in 1974
Damage: Shear cracks in the beams of 2nd and 3rd floors were observed.


South side view


Shear cracks in beams

[Commercial building]
Building: Commercial building A
Location: Kumamoto city, central district
Structural specification: 4-story RC building
Damage: Shear failure was observed in the columns of 1st to 3rd floors. The longitudinal and transverse reinforcement consisted of plain round bars. The non-structural RC walls failed in shear.

West side view

Shear failure of the column

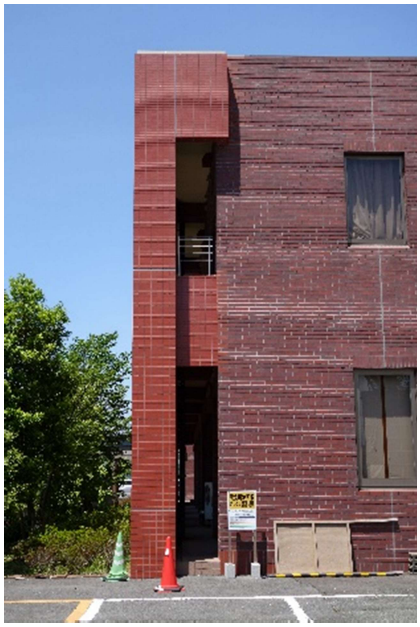
Shear failure of the column on the 2nd floor
(Plain round bars and lap splices are seen)

Shear failure of non-structural RC walls

[Governmental building]
Building: Governmental building A
Location: Kikuyo town
Structural specification: 3-story RC building with 15 x 2 bays, retrofitted by attaching precast prestressed concrete or PCaPC moment resisting frames in 2011. The building was operational and in service.
Damage: No damage was seen either in the attached PCaPC frames or the main structure. A 1.0 cm uplift was seen in the wall base in the eastern wing. Shear cracks in non-structural walls of the long side inside the builing were observed.


South-east view


South-west view


PCaPC frame (left) and main structure (right)


1.0 cm uplift at the wall base

Building: Governmental building B
Location: Kashima town
Structural specification: 3-story RC (partially PC) building, built in 1997.
Damage: Some material fallings were seen at the entrance hall near the ceiling. The ground outside the building deformed.

North view

Ceiling materials

Deformation of the ground outside

Building: Governmental building C
Location: Kumamoto city, south district
Structural specification: 3-story RC (partially PC) building with 12 bays in the long side and 3 bays in the short side
Damage: The building was operational and in service. No serious damage was observed. The ground outside was partially settled.

North view

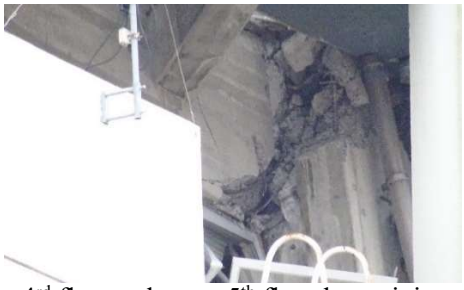
Partial ground settlement at the main entrance

Building: Governmental building C
Location: Uto city
Structural specification: 5-story RC building, built in 1965
Damage: The 4th story partially collapsed. The crushing in beam-column joints at several places of the 3rd and 4th stories was observed. The crushing of a joint in the 4th story resulted in the upper part (column and slab) displaced downward. Due to the joint failure at the 5th floor, the beam in this floor deflected downward as well.


West view


3rd and 4th floors


3rd floor column - 4th floor beam joint


4rd floor column - 5th floor beam joint

Building: Governmental building E
Location: Uki city
Structural specification: 3-story 12×2-bay RC (partially PC) building with the penthouse, built in 1994
Damage: The building was operational and in service. Ground settlement was seen at several spots. Shear cracks were seen in the external walls in the short span side.


West view


Ground settlement

The annex builidng was a 3-story RC building, built in 2007. It was connected to the main building via a corridor in the 2nd floor. No damage was observed. However, a settlement of about 30 cm occurred in the ground.

West view

Ground settlement

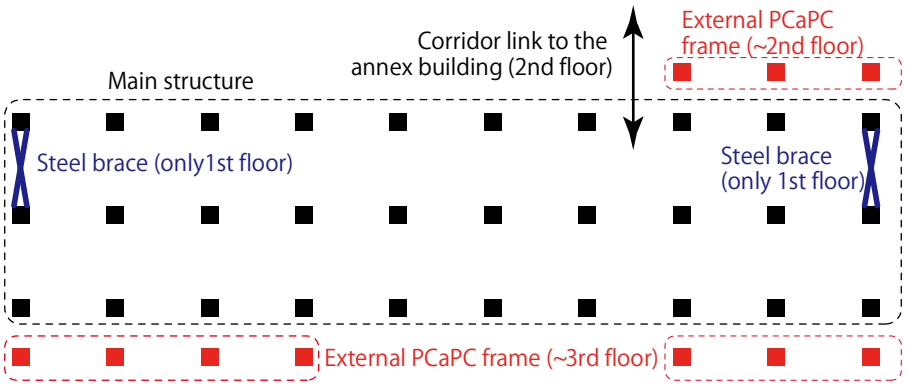
Building: Governmental building F
Location: Uki city
Structural specification: 3-story 9×2 span RC building, retrofitted with external PCaPC frame and steel bracing methods.
Damage: The main building was almost intact. Cover plates over the expansion joint between this main building and a neighboring steel structure was partially displaced. The PCaPC frame was connected to the existing building structure with a beam approximately 3000 mm long. In addition, ground settlement was observed.

West side

Displaced steel cover of expansion joint

Ground condition

Steel-braces for retrofitting



Column arrangement and the seismic retrofitting

Building: Governmental building G
Location: Uki city
Structural specification: 2-story 5×3-bay RC building
Damage: No damage was noticed from outside. The building was operational.


SouthWest view

Building: Governmental building H
Location: Kumamoto city, central district
Structural specification: 4-story 7×2-bay RC building, retrofitted by precast prestressed concrete moment resisting frames in 2010.
Damage: In the long direction of the building and the opposite side of the retrofitted face, some shear cracks were observed in the wing walls. Some minor cracks were observed in the columns as well. Some horizontal cracks occurred at the columns bases in the transverse direction. Some evidence of ground settlement was noticeable.


North-east view


Crack in wing wall

Shear crack in column

Horizontal crack at column base

[Cultural center and Gymnasium]
Building: Gymnasium A and cultural center A
Location: Kikuyo town
a) Gymnasium A
Structural specification: 2-story RC building with steel-framed roof, built in 1973. The building was attached to the adjacent building from its second floor without any noticeable structural separation.
Damage: Due to falling of the ceiling materials and linings, the gym had been closed. The glass of the windows, however, did not break. Some hexagonal cracks, probably due to shrinkage of ageing concrete on the columns of the second floor, were seen. Along those cracks, there were some other cracks, as wide as 1 mm, which were assumed to occur during the earthquake. The shear wall behind the stage of the gym had shear cracks. The pathway to the adjacent building suffered some damage as well.


North side view


Interior view (ceiling linings are deflected)


Damage to the ceiling materials


Damage to the ceiling materials of the stage


Flexural crack in column of 2nd floor


Shear crack in shear wall of 2nd floor

Damage at joint of the two buildings

b) Cultural center A

Structural specification: 3-story 7×2 span RC building with a penthouse. built in 1972. The building was retrofitted in 2010 by steel braces located in the first and second floors.

Damage: Almost all the non-structural RC walls had damage. The third floor, with no steel braces, had cracks with large width compared to cracks in the lower two floors. The maximum crack width of the shear walls in the longitudinal directions of the building at the first and third level were 0.45 mm and 3 mm, respectively.

North side view

Steel braces for retrofitting.

Cracks in non-structural RC wall

Crack in shear wall in 3rd floor

Building: Gymnasium B

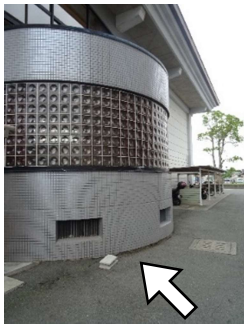
Location: Kumamoto city, Sothern district

Structural specification: 2-story RC building.

Damage: This building was being used as a shelter. Some ground settlement was seen around the building. Some minor cracks were found in the shear walls along the transverse direction. These cracks were not confirmed as being a result of the earthquake.

North-east view

Crack in shear wall



Ground settlement

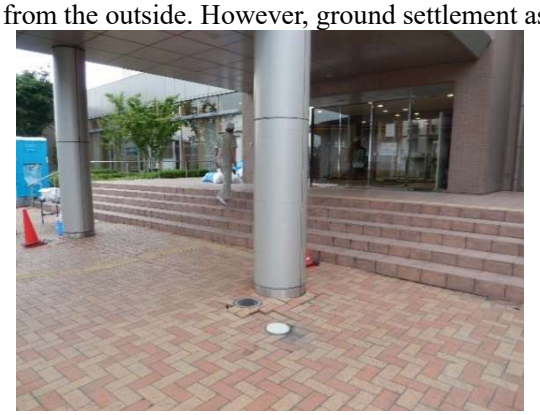
Building: Cultural center B
Location: Kashima town, Kamimashiki district
Structural specification: 3-story RC/Steel building with partially prestressed concrete members built in 2014.
Damage: A crack in the glass facade next to the entrance was seen. Some settlement in the surrounding ground was noticed.


Outside view


Ground settlement


Crack in the glass facade

Building: Cultural center C
Location: Kumamoto city, southern district
Structural specification: RC/Steel building, built in 2003.
Damage: This building was partially used as an evacuation shelter. No major damage was found from the outside. However, ground settlement as large as 10 cm around the building was observed.


Damage in the external floor.


Ground deformation.

Building: Cultural center D
Location: Uki city
Structural specification: 2-story SRC (partly steel structure), opened in 1998.
Current condition: This building was used as an evacuation shelter after the earthquake.


North side view

Building: Cultural center E
Location: Kumamoto city, central district
Structural specification: 5-story RC (steel structure in part) with the basement, built in 1994.
Damage: Shear cracks occurred in the shear walls of the 1st floor next to the entrance. Some cracks were noticeable around the perimeter of the circular opening of the non-structural RC wall.


East side view

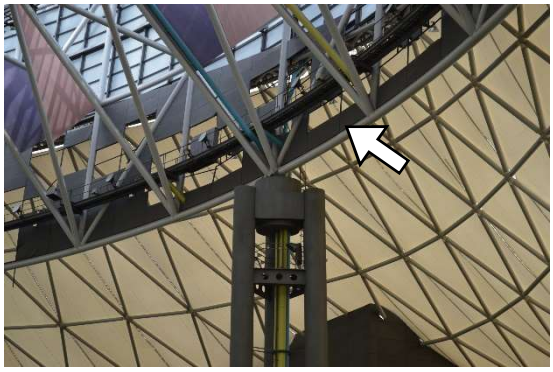

Shear crack in shear wall


Shear crack in the external non-structural RC wall

[Sport center]
Building: Sport center A
Location: Kumamoto city, Eastern district
Structural specification: A steel gymnasium with a membrane roof built in 1997. A two story RC office building was also inspected.
Damage: This facility is currently closed to public. Some concrete spalling occurred in the exterior RC walls of the office building. Ceiling materials in the gym were partially loosened and had fallen down.


South view


Damage to exterior RC wall


Falling of ceiling materials


Fallen ceiling materials on the ground floor

Building: Sport center B
Location: Kumamoto city, Eastern district
Structural specification: RC/PC structure with seven stories and the basement, built in 1998.
Damage: No damage was seen from outside.


Far sight view from north-east

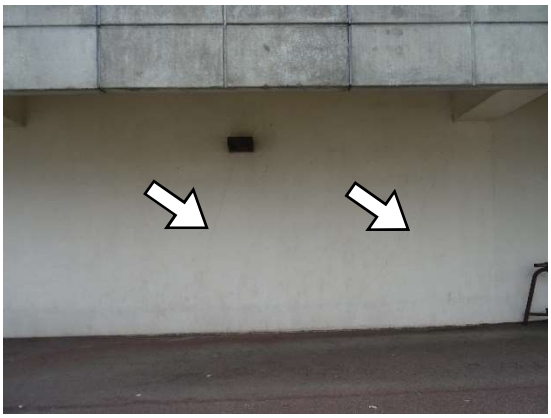

Outside view

Building: Sport center C
Location: Kumamoto city, Central district
Structural specification: RC/Steel structure.
Damage: The main entrance of the facility was under seismic retrofitting when the earthquake occurred. The builidng was tagged as “unsafe” by post-earthquake temporary risk evaluation. Some retaining walls collapsed. The stand was severely damaged and the exterior walls accomodated extensive cracks.

Damage to stand

Damage to retaining wall

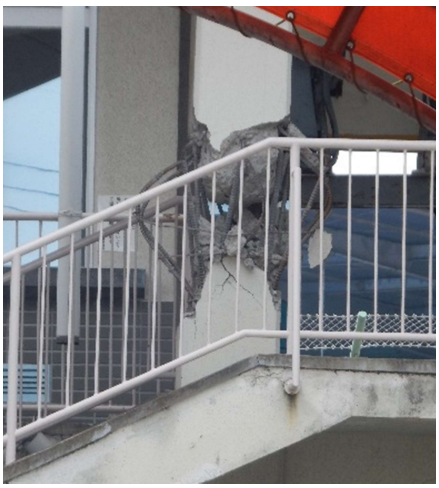
Collapse of retaining wall and surrounding ground.



Crack in exterior walls

Building: Sport center D
Location: Kumamoto city, Central district
Structural specification: This facility is composed of three buildings that were built in 1968, 1972, and 1981.
Damage: The whole structure was judged as “unsafe”. A number of RC columns of the stand which was built in 1968 suffered shear/flexural failure. In some steel frame structures the infill panel were eaither cracked or shattered.

East view



Shear collapse of column

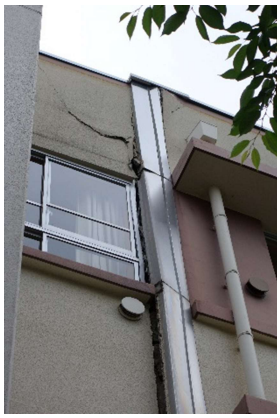
Flexural failure at column base

Damage to infill panel of steel structure and crack in the first floor walls

[School]
Building: School A
Location: Kumamoto city, Eastern district
Structural specification: 3-story RC structure. The building was seismically retrofitted with spatial outer frames and external PCaPC or Precast Prestressed Concrete plane frame.
Damage: Damage at the expansion joint was significant. Some diagonal cracks were observed at the joints of the outer frames, but it was not confirmed whether these occurred due to the earthquake or not. Shear cracks were noticeable in the longitudinal direction of the building where the external PCaPC frames were attached to the existing builidng.

Seismic strengthening with PCaPC outer frame

Seismic retrofit with plane frame and cables.



Damage at expansion joint

Cracks in external RC walls in non-strengthened direction

Crack at joint of retrofitting plane frame

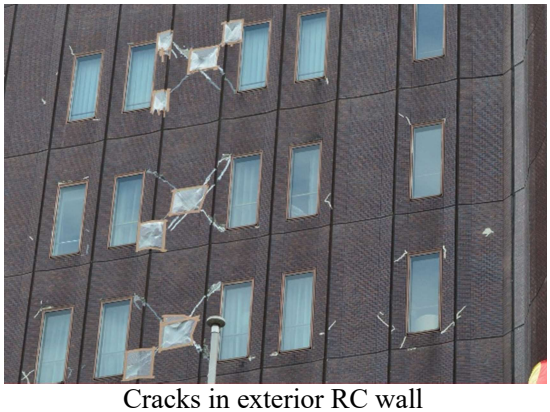
Column base at corridor

Building: School B
Location: Kumamoto city, Central district
Structural specification: 5-story RC structure with a penthouse and one basement floor. The building was seismic retrofitted with precast post-tensioned concrete braces.
Damage: No damage was observed from the external inspection of the building. Slight ground settlement occurred at the entrace.

South side view

[Hotel]
Building: Hotel A
Location: Kumamoto city, Central district
Structural specification: 11-story SRC structure with one basement story, built in 1975.
Damage: Extensive damage to the exterior RC walls was noticed.

North-west view

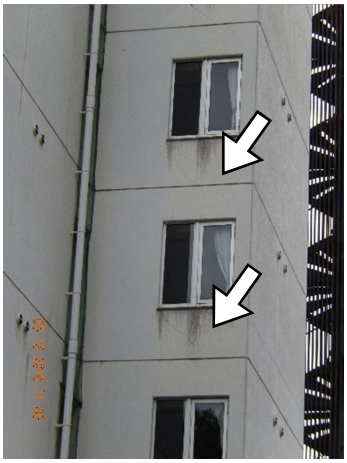


Cracks in exterior RC wall

Building: Hotel B
Location: Kumamoto city, Central district
Structural specification: 11-story RC structure with a penthouse, built in 1982.
Damage: The building was apparently vacant. Extensive cracks in the RC walls between window openings were observed. In addition, some diagonal cracks were noticed in the beam above the entrace.

North-west side view

Diagonal cracks in exterior RC walls between window openings



Cracks in exterior RC walls between window openings

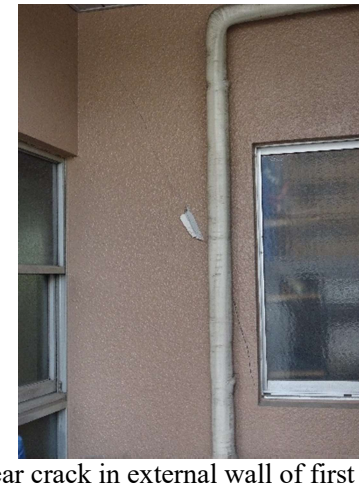
Shear cracks in the beam at the main entrance

Building: Hotel C
Location: Kumamoto city, Central district
Structural specification: 6-story RC structure, built in 1969. The building was seismically retrofitted in 2014 with PCaPC spatial outer frames, additional walls and structural separation called *slit*.
Damage: The building was open to public. Shear cracks were found in the external wall of the first story and the retrofitting frames. Moreover, cracks in the beam-column connections were seen.

East side view

Spatial outer frames for retrofitting

Crack at beam-column connection



Shear crack in external wall of first floor

[Clinic]
Building: Clinic A
Location: Kumamoto city, Central district
Structural specification: 3-story RC structure.
Damage: The first floor collapsed. Lap splices of steel reinforcement were seen at the top of columns of the 1st floor.

South-east side view

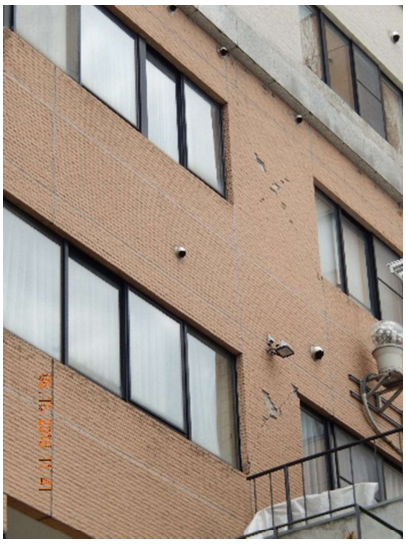
Lap splices at the top of the collapsed column in the 1st floor

[Other buildings]
1. Damage to RC walls

Cracks in the 1st and 2nd floors (Kumamoto city, central district)

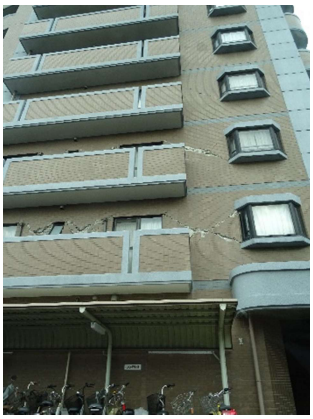
Cracks in non-structural RC walls of the 2nd floor（Kumamoto city, central district）

Non-structural RC walls cracked（Kumamoto city, central district）



Diagonal cracks in non-structural RC wall (Kumamoto city, central district)

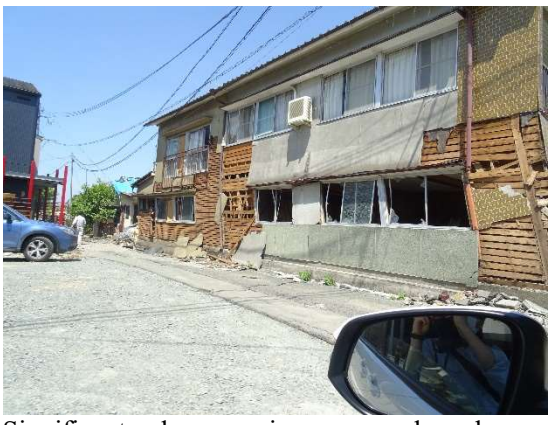
Cracks at the base of shear wall（Kumamoto city, East district）



Diagonal cracks in non-structural RC wall（Kumamoto city, East district）

2. Timber and Steel buildings

Collapse of a wooden house
（Kumamoto city, central district）



Significant damage in a wooden house, Kamimashiki district, Mashiki town

Collapse of a wooden temple (Kamimashiki district, Mashiki town)

Damage to exterior panels and falling of window glasses (Kumamot city, Eastern district)

3. Damage to roads and pathways

Elevation difference between bridge and roadway (Kumamot city, Eastern district)

Sinking of pavement (Kumamoto city, Eastern district)

4. Damage to Kumamoto castle (Kumamoto city, central district)

Collapse of a shrine

Damage to stone retaining wall (Kumamoto city, central district)

Damage to stone retaining wall

Rotation of stone monument

Spalling and cracking in the soil wall

Damage to stone retaining wall

5. Other

Damage to RC structure of the entrance gate to a shrine (Kumamoto city, central district)

Damage to RC structure of the entrance to a shrine gate (Kumamoto city, central district)

Damage to a temple gate (Kumamoto city, central district)

Collapse of concrete block wall (Kumamoto city, central district)

Collapse of a stone monument (Kikuyo town)

Tilting of a roof water supply (Kumamoto city, East district)