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Effect of Underground Beam on Seismic Damage of Railway Rigid Frame Viaduct

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Today's Topics

1. Introduction

- Difference in degree of damage between two railway rigid frame viaducts in 2016 Kumamoto earthquake.

  * These structures adjacent to each other
  * The Structure with underground beams➔ No damage
  * The Structure without underground beams➔ Crack of column

2. Investigate the seismic response of two structures by numerical analysis

➔ Found the factor of the difference in the degree of damage

3. Evaluate the effect of ground displacement and inertia on two structures with/without underground beams

4. Conclusion

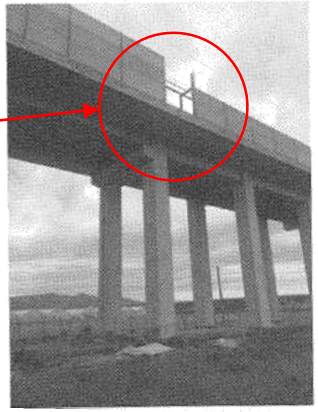
Introduction

In the 2016 Kumamoto earthquake, large acceleration were recorded along the railroad

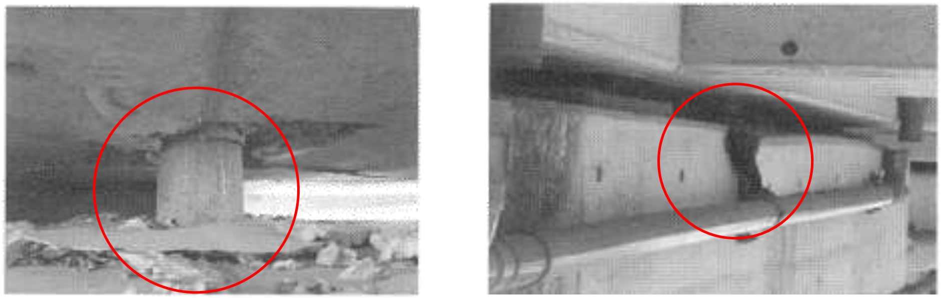
- Shinkansen vehicles were derailed
- Bearings and noise barrier were damaged
- Main members (columns, beams) were not serious damaged.

derailment of Shinkansen

Noise barrier



Bearing and stopper



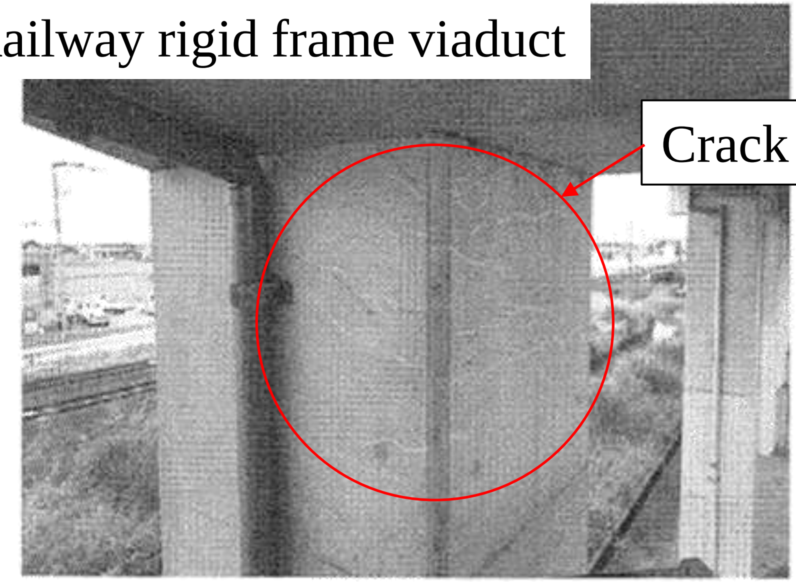
Introduction

In the 2016 Kumamoto earthquake, large acceleration were recorded along the railroad

- Shinkansen vehicles were derailed
- Bearings and noise barrier were damaged
- Main members (columns, beams) were not serious damaged.

➔ At most, crack of columns occurred

Railway rigid frame viaduct



Introduction

Difference in degree of damage to adjacent viaduct was confirmed.

Structure A

adjacent to
each other

Structure B

These structures were

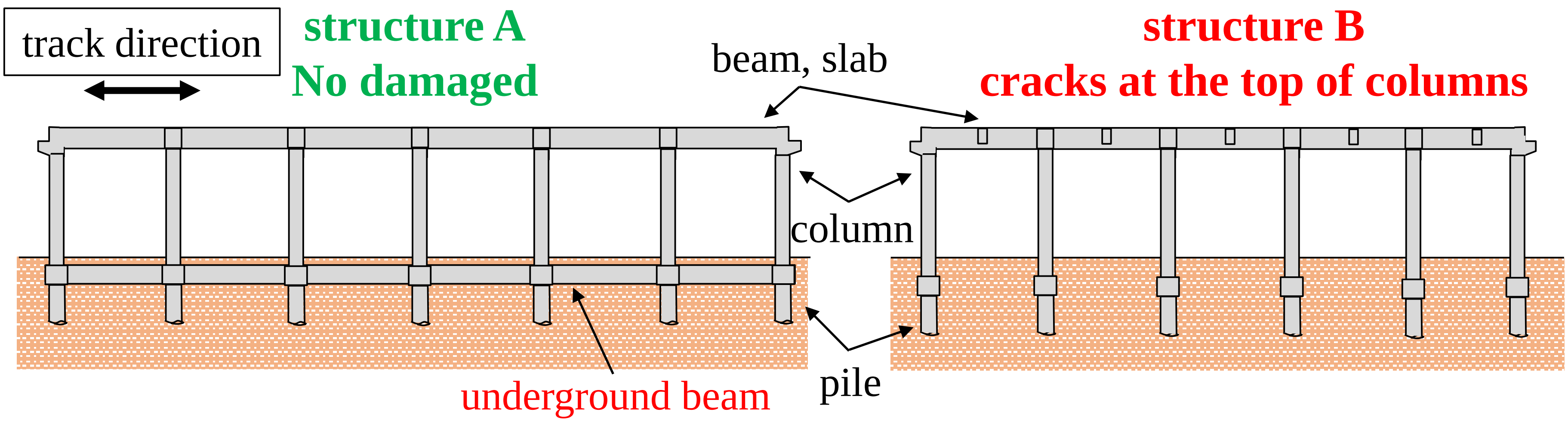
- constructed at the same point ➔ Same ground condition and ground motion
- designed by same seismic standard ➔ Same required performance

Introduction

Some structural characteristics were different.

- presence/absence of underground beams in track direction
- length of span, section of column

⇒ Factors of difference of damage?



Structural characteristics	Structure A (with underground beam)	Structure B (without undergrounf beam)
Number of Span	6	5
Height of structure	10.8m	11.8m
Length of span (transverse)	9.3m	4.8m
Section of column	0.9m×0.9m	1.3m×1.3m
Foundation type	Cast-in-place pile	Steel pipe pile

Overview of study

Investigate the seismic response of these structures and found out the factors of the difference in the degree of damage

adjacent to
each other

- Analytical modeling (2-dimensional frame model)
- Comparing periodic characteristic and failure mode (Push-over analysis)
- Comparing seismic behavior under the Kumamoto earthquake (Dynamic analysis)
- Evaluating the each effect of inertia and ground displacement.

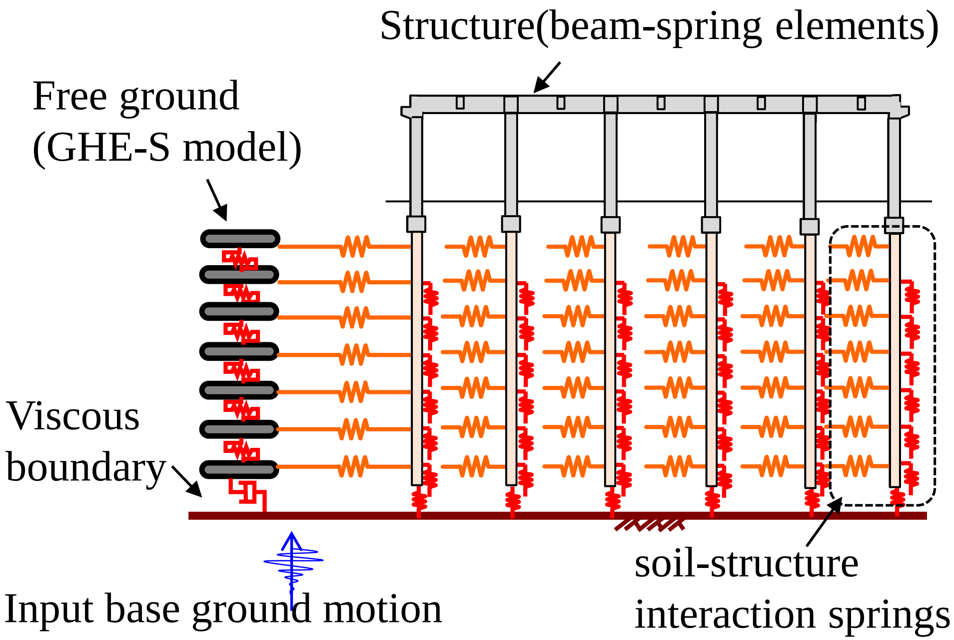
Estimated factors are
・Effect of periodic characteristic?
・Effect of inertia? / Effect of ground displacement?

Analytical modeling

2-dimensional frame model was constructed.

- modeling direction: **track direction**
- members and soil-structure interaction: **beam-spring elements**
- **nonlinear characteristics**: according to the current design standard in Japan
- model of free ground: **GHE-S model**

Integrated model



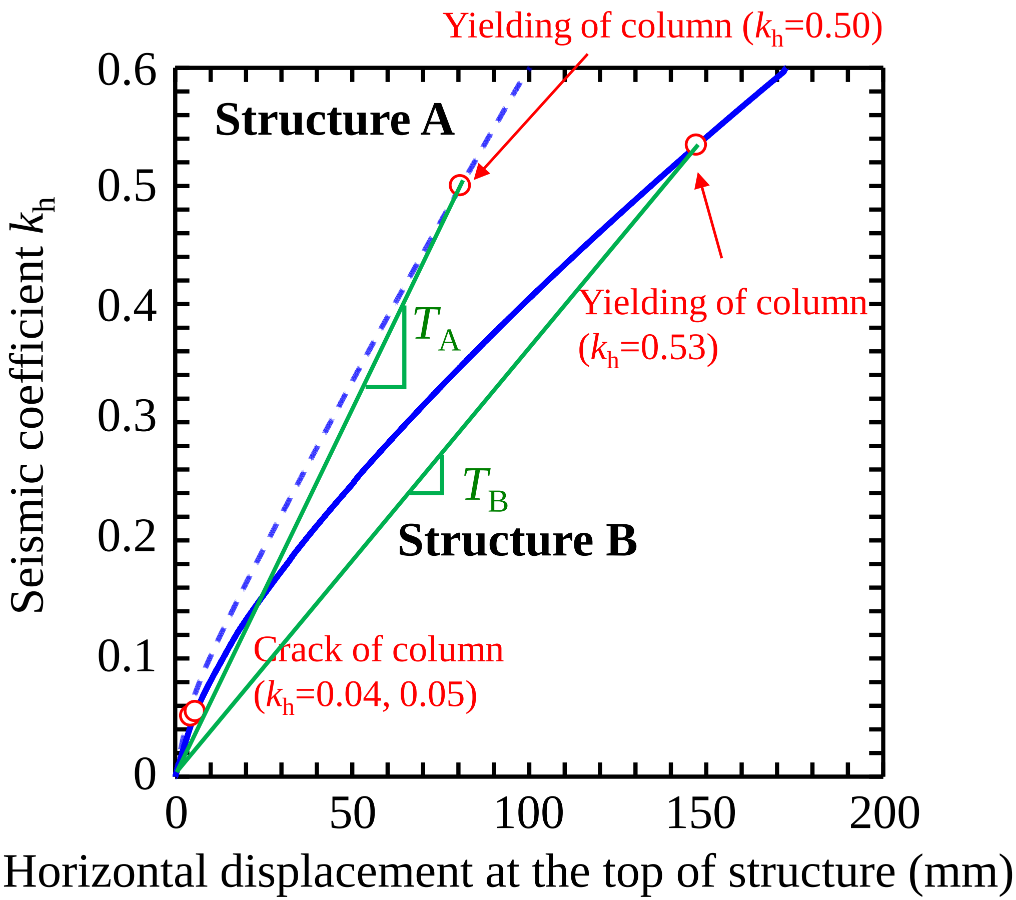
Ground condition

Layer thickness (m)	Soil type	N-value	C (kN/m^2)	φ (deg)	γ (kN/m^3)	V_s (m/s)
2.7	clay 1	3	18	0	15	130
4.8	sand 1	5	0	26	17	137
2.0	clay 2	10	44	0	15	215
6.4	sand 2	19	0	33	18	213
4.0	clay 3	3	74	0	15	144
3.9	gravel 1	20	0	34	18	326
9.9	gravel 2	20	0	34	18	380

Periodic characteristics and Failure mode

Push-over analysis was performed.

Horizontal force-displacement relationship



Failure event and calculated value

properties	A	B
Seismic coefficient of crack	0.04	0.05
Seismic coefficient of yielding	0.50	0.53
Yielding displacement	81mm	147mm
Natural period T	0.8s	1.0s

- Failure mode is same; damage of columns are progressed

- Seismic capacity is almost equal

- Periodic characteristic is different; $T_A > T_B$

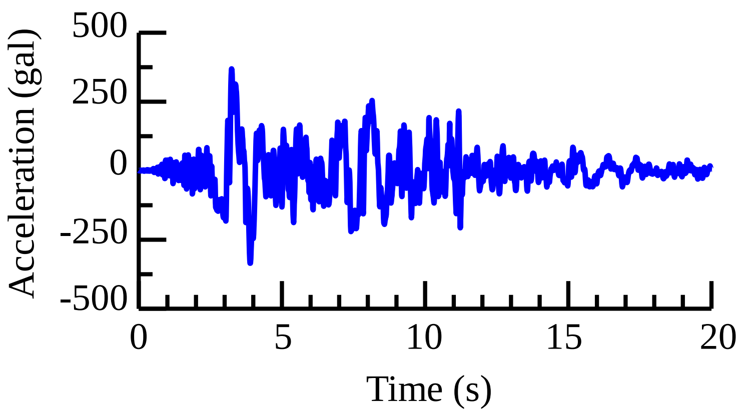
These structures have almost the same seismic capacity, but the periodic characteristic are different.

Seismic response under the Kumamoto eathquake

Analytical condition;

- Calcurate input base ground motion by using recorded surface ground motion.
- Newmark's β (β=1/4) method, time step is 0.001s

Recorded surface ground motion



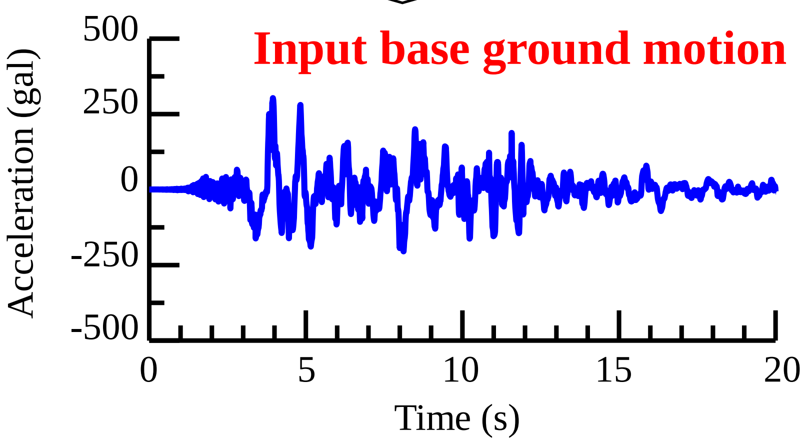
+

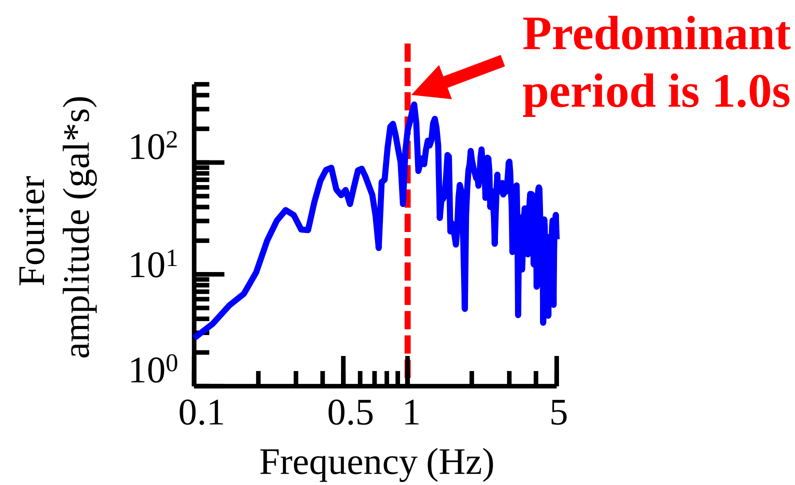
Ground condition at the recorded point

Depth (m)	Soil type	N-value	V_s (m/s)	γ (kN/m^3)	D50 (mm)
0.0~3.2	clay	6	130	16	0.020
3.2~5.3	soil	18	170	19	0.150
5.3~7.2	silt	2	170	16	0.025
7.2~8.8	soil silt	2	230	16	0.040
8.8~18.6	soil	32	230	19	0.150
18.6~23.0	silt	4	160	16	0.025
23.0~25.9	soil	7	160	19	0.150
25.9~26.1	clay	31	225	17	0.020
26.1~29.5	soil	31	225	19	0.600
29.5~34.6	gravel	44	440	19	2.000
34.6~35.7	soil	33	440	19	0.600

Equivalent linearized method

Input base ground motion





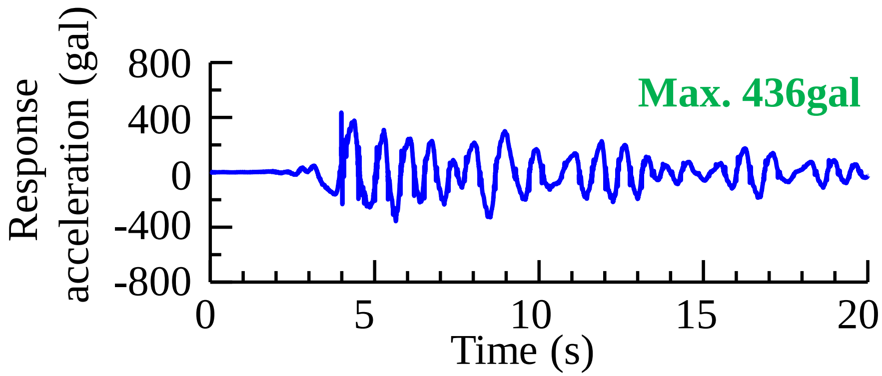
Seismic response under the Kumamoto eathquake

Response of structure B was larger than structure A.

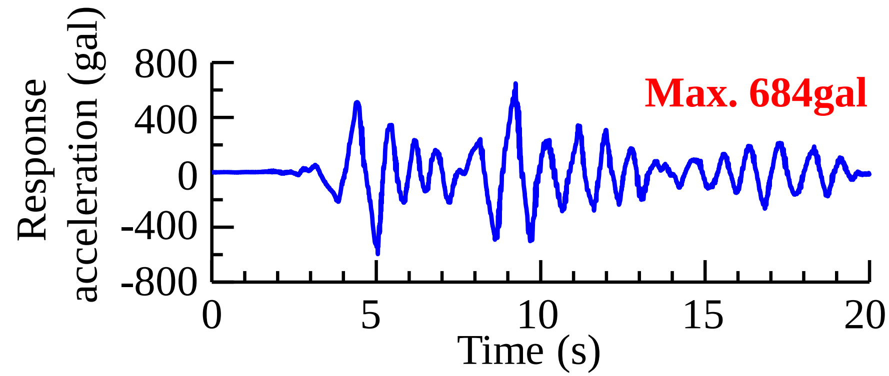
➔ This magnitude relationship is consistent with the actual case

- Response acceleration

Structure A (with underground beams)

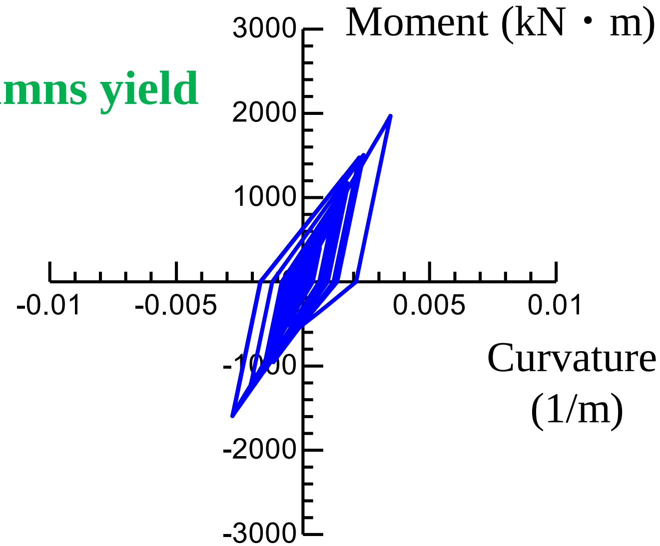


Structure B (without underground beams)



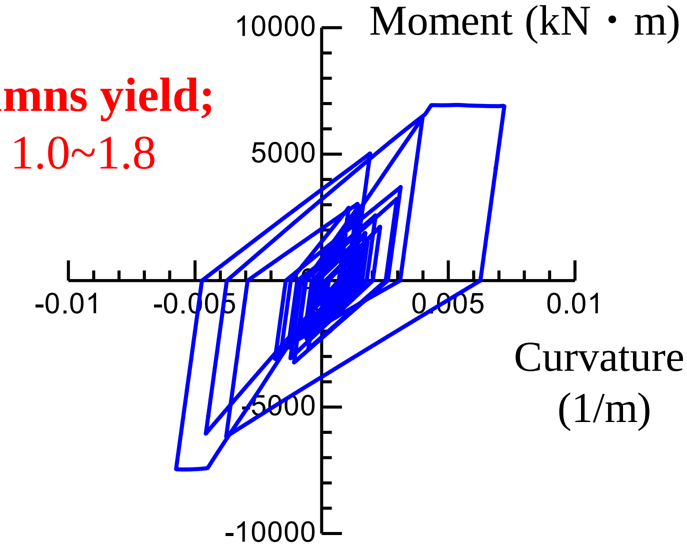
- Maximum response of column

➔ No columns yield



➔ All columns yield;

Ductility is 1.0~1.8



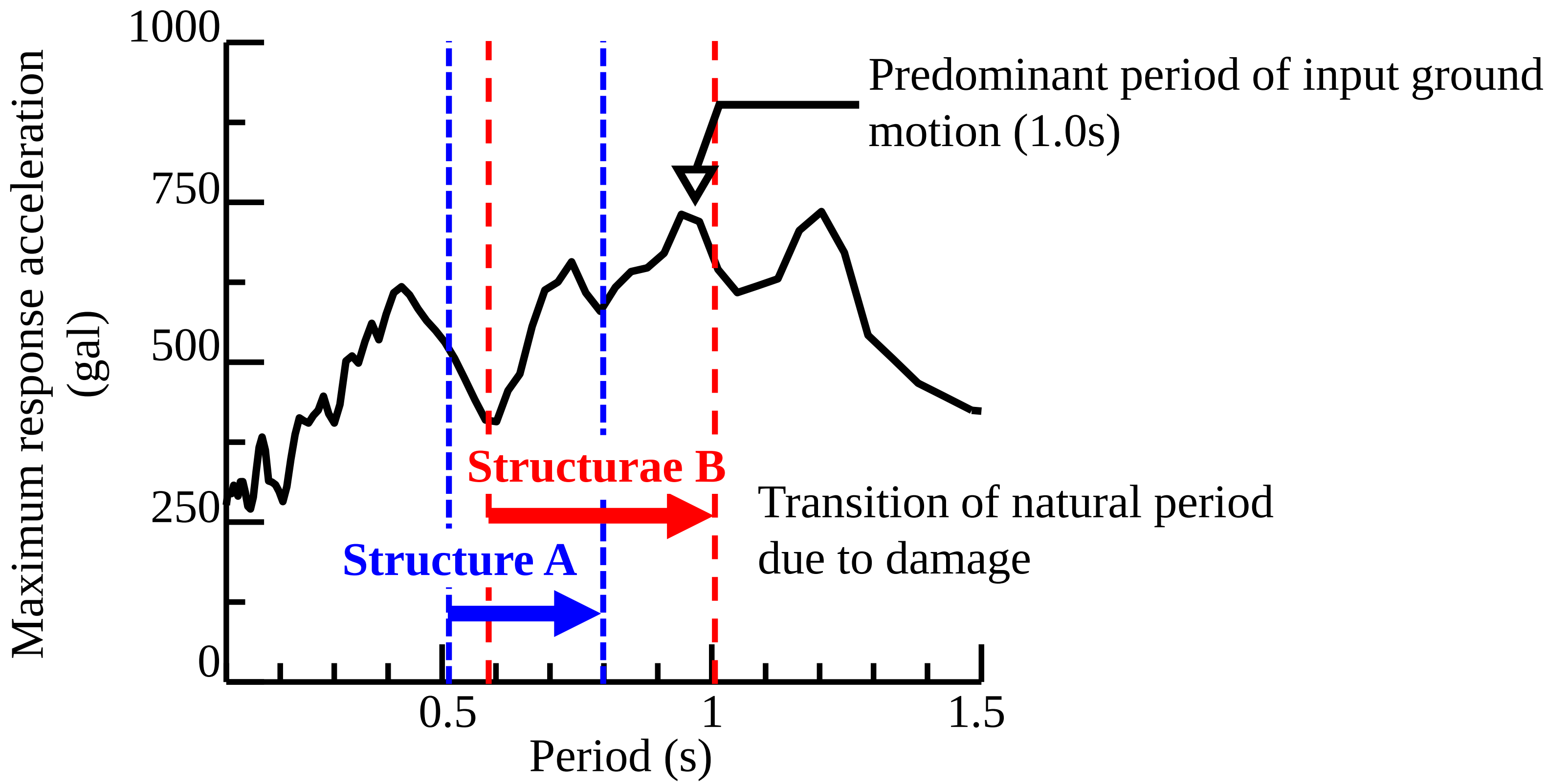
What makes a difference?

Natural period of structures
A: 0.5s～0.8s (elastic～yielding)
B: 0.6s～1.0s (elastic～yielding)

Predomintan period of ground motion: 1.0s

more close

Relationship between predominant period and natural period

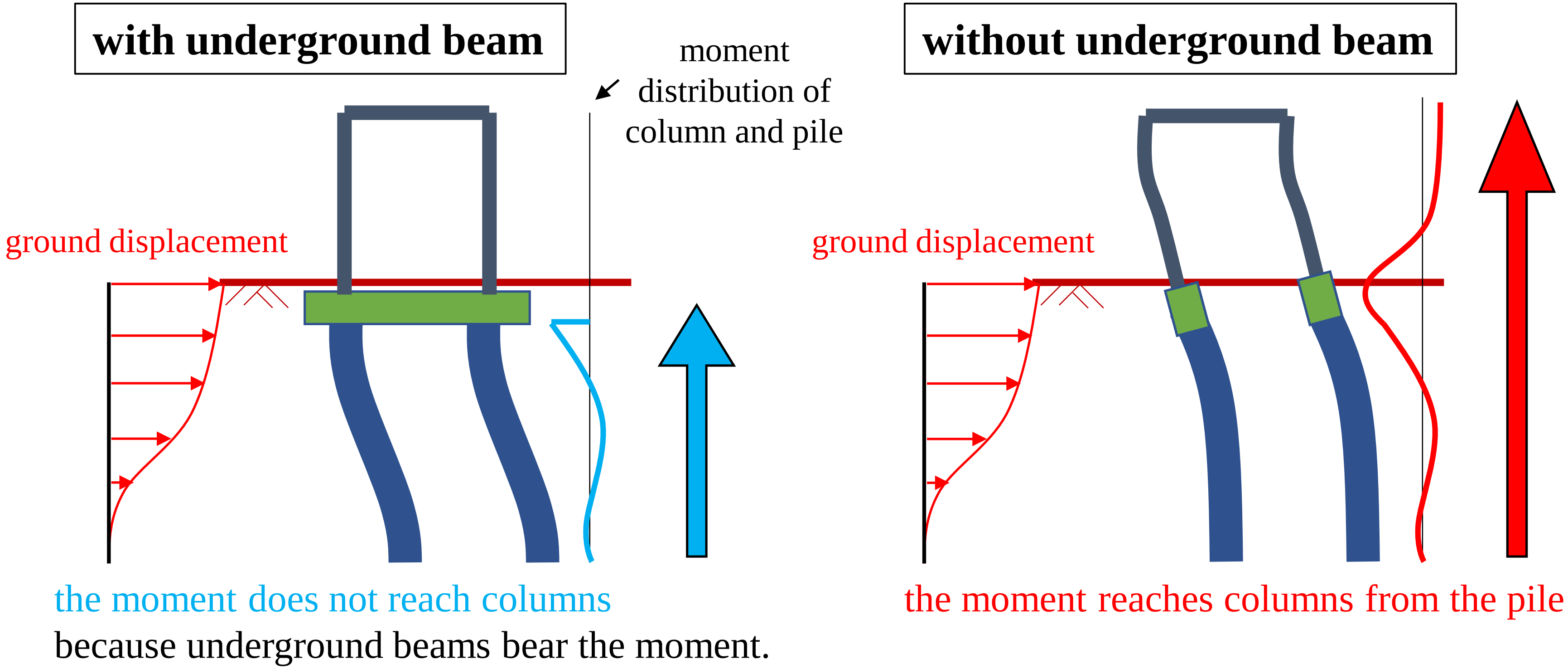


Periodic characteristic was one of the factor of difference in damage

Are there other factors?

It seems that the **periodic characteristic (consistency of natural period and predominant period)** is one factor of difference in the damage.

In case of a structure without underground beams (pile-bent), it is known that **the response moment by the ground displacement reaches columns.**



It is possible that the response of target structures were also affected by the ground displacement.

Analytical modeling

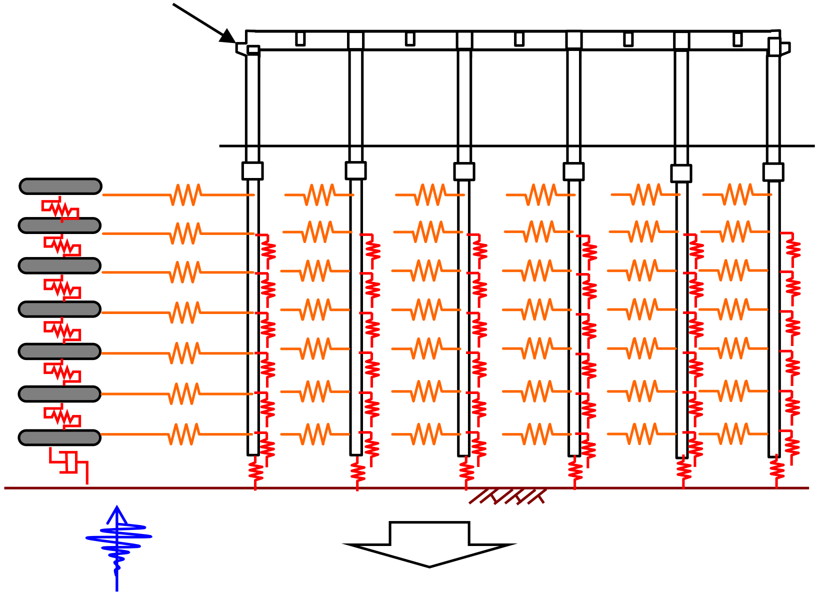
Evaluate the effects of ground displacement and inertia on the seismic response

Reference model (whole system model)

- Both inertia and ground displacement are generated .

ground system model

Viaduct: set mass to zero

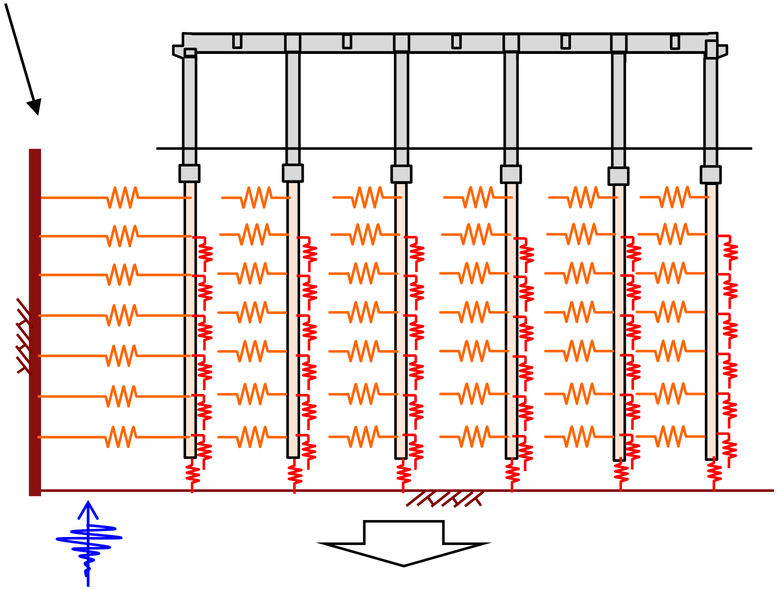


- Inertia is NOT generated

➔ response by the effect of ground displacement

Inertial system model

Free ground: Restrict ground displacement



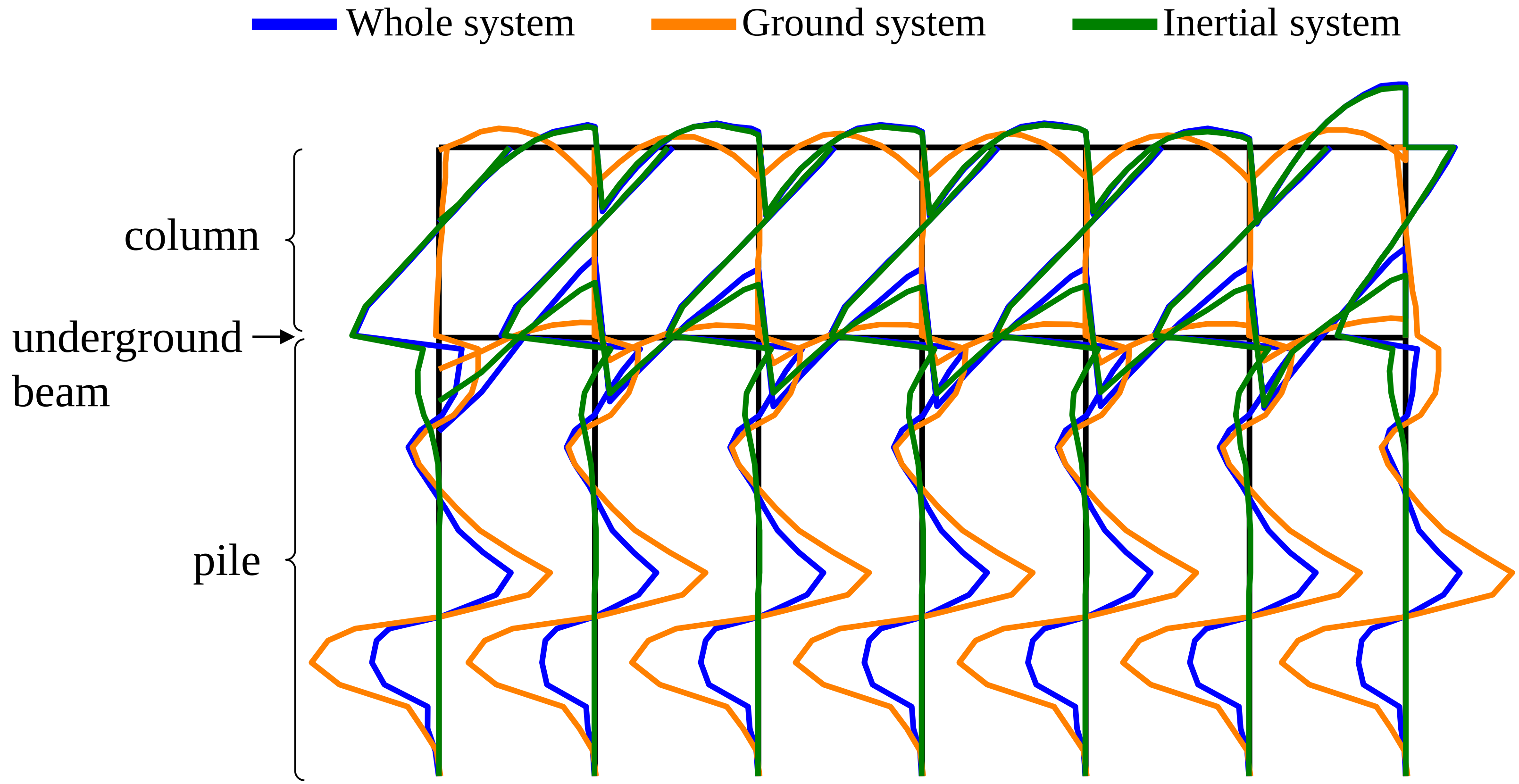
- Ground displacement is NOT generated

➔ response by effect of inertia

Comparison of moment distribution

Maximum response moment distribution under the Kumamoto earthquake

Structure A with underground beam



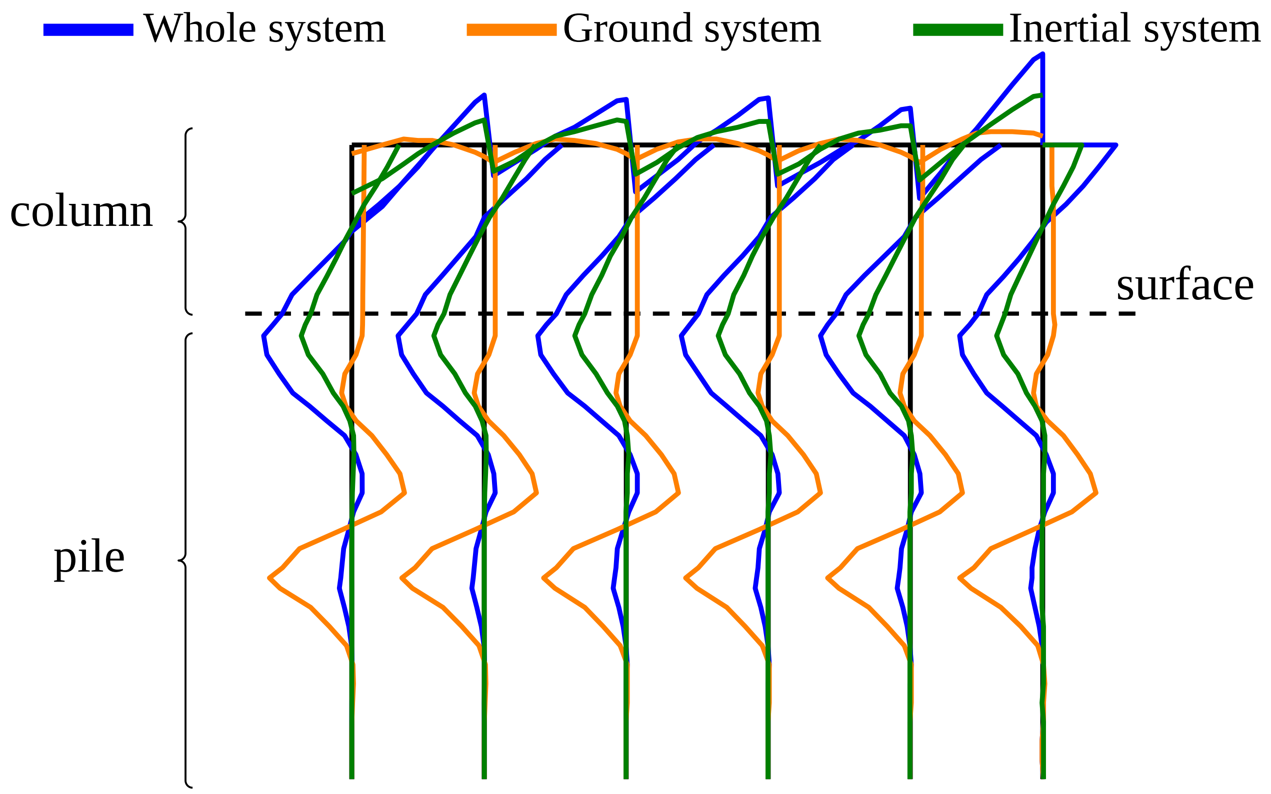
Ground system model ➔ only from **pile to underground beam**

Inertia system model ➔ from **column to top of pile**

Comparison of moment distribution

Maximum response moment distribution under the Kumamoto earthquake

Structure B without underground beam



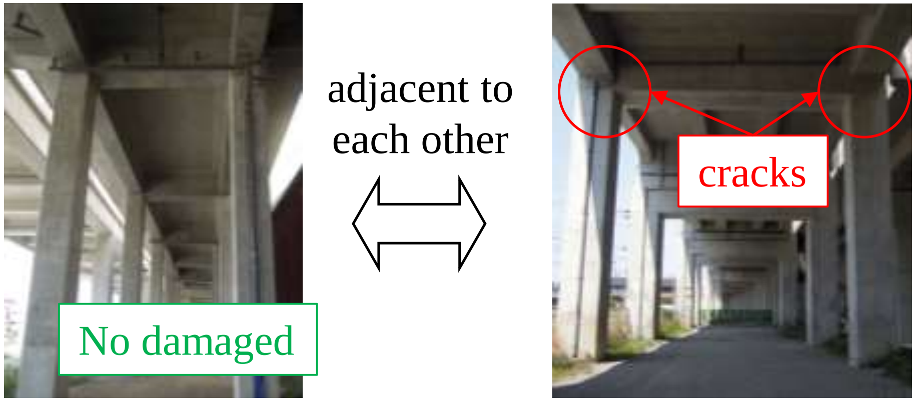
Ground system model
Inertia system model

➔ **wide distribution from pile to top of column**

The response moment caused by ground displacement was another factor of difference in damage

Conclusion

The response of two railway rigid frame viaducts, which differed in the degree of damage in the 2016 Kumamoto earthquake were evaluated



- Analytical modeling
- Comparing periodic characteristic and failure mode
- Comparing seismic behavior under the Kumamoto earthquake

It was clarified that one factor that caused a difference in the degree of damage of these structures in the Kumamoto earthquake was that the **natural period of structure without underground beams was closer to the predominant period of the ground motion** than that of the other structure with underground beams.
Furthermore, **the effect of the ground displacement on the response of columns of structure without underground beams** was another factor.

Thank you for your time and attention