Study on Seismic Effect and Mechanism of TOBs in Girder Bridges with High Piers

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Outline

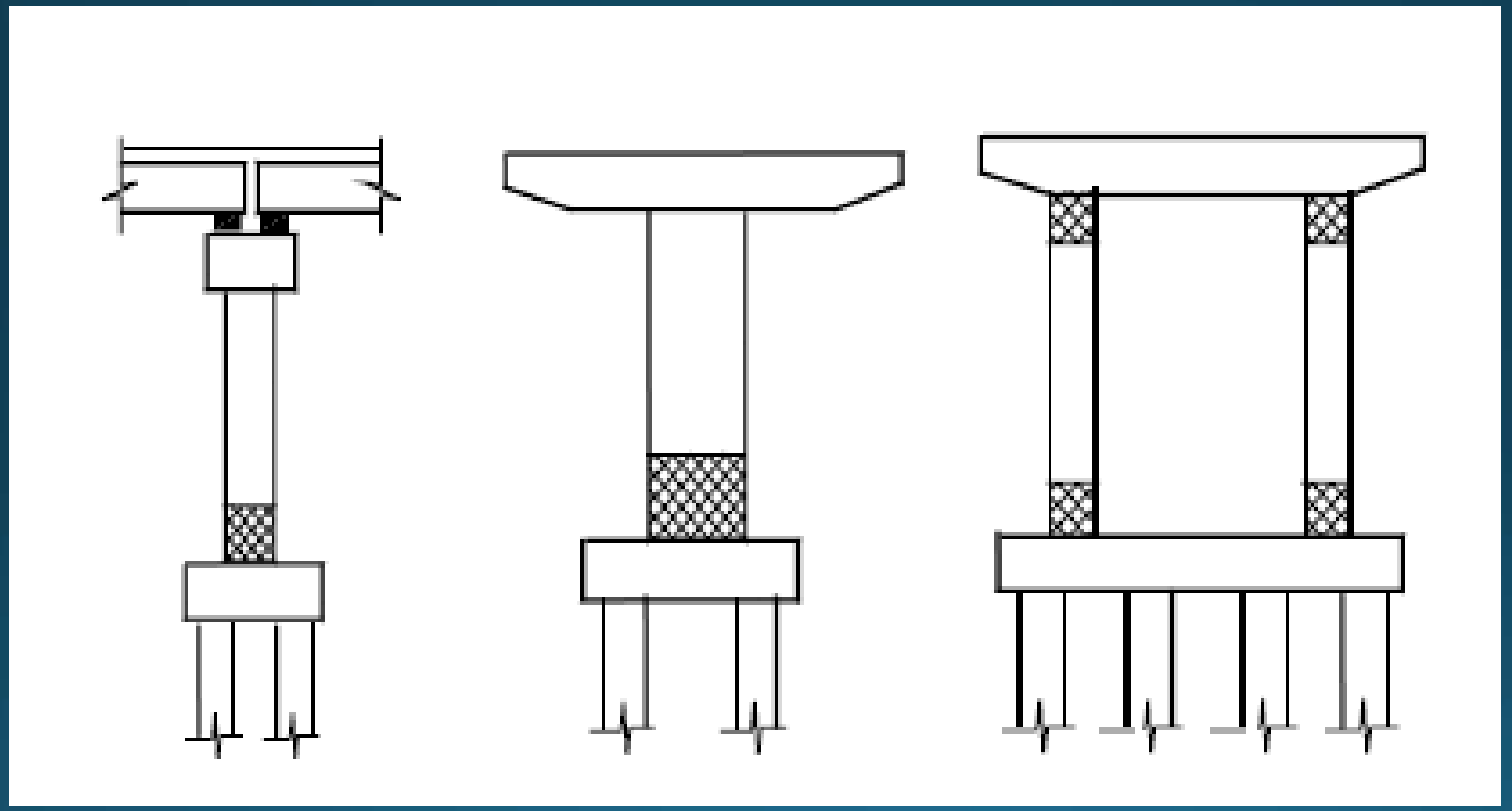
- 1. Introduction
- 2. Concept development of TOBs
- 3. Numerical Simulation Analysis
- 4. Seismic Effect and Mechanism Analysis of TOBs
- 5. Conclusions

1. Introduction

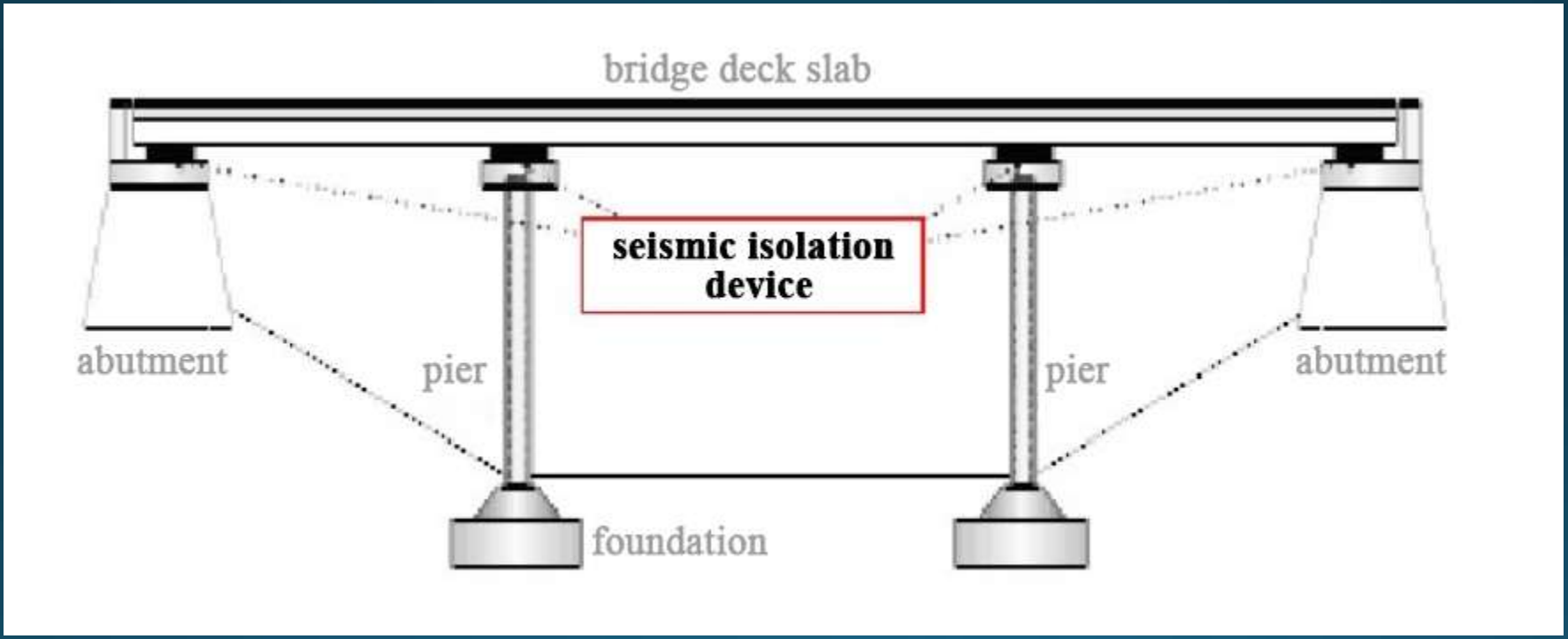
- With the constantly improvement of Chinese road facilities and the starting of Western Great Development, bridges constructed in southwest China are more and more.
- According to statistics, bridges with over 40 meters high piers account for more than 40% of the total number of bridges in Southwest China, and the maximum pier height is up to 143m.
- Once bridges with high piers get damaged or even collapsed during earthquakes, the direct financial loss is several times greater than common bridges.

- There are two frequently used seismic design methods for common bridges: the seismic isolation design method and ductility design method.
  - Usually, high pier bridges belong to flexible structures, which have a long natural vibration period. Therefore, the seismic isolation design method has few applications in bridges with high piers.
  - high pier bridges under the ductility design method may suffer seismic damage unavoidably, and post-earthquake rehabilitation is much harder in such mountainous areas.

Capacity design method

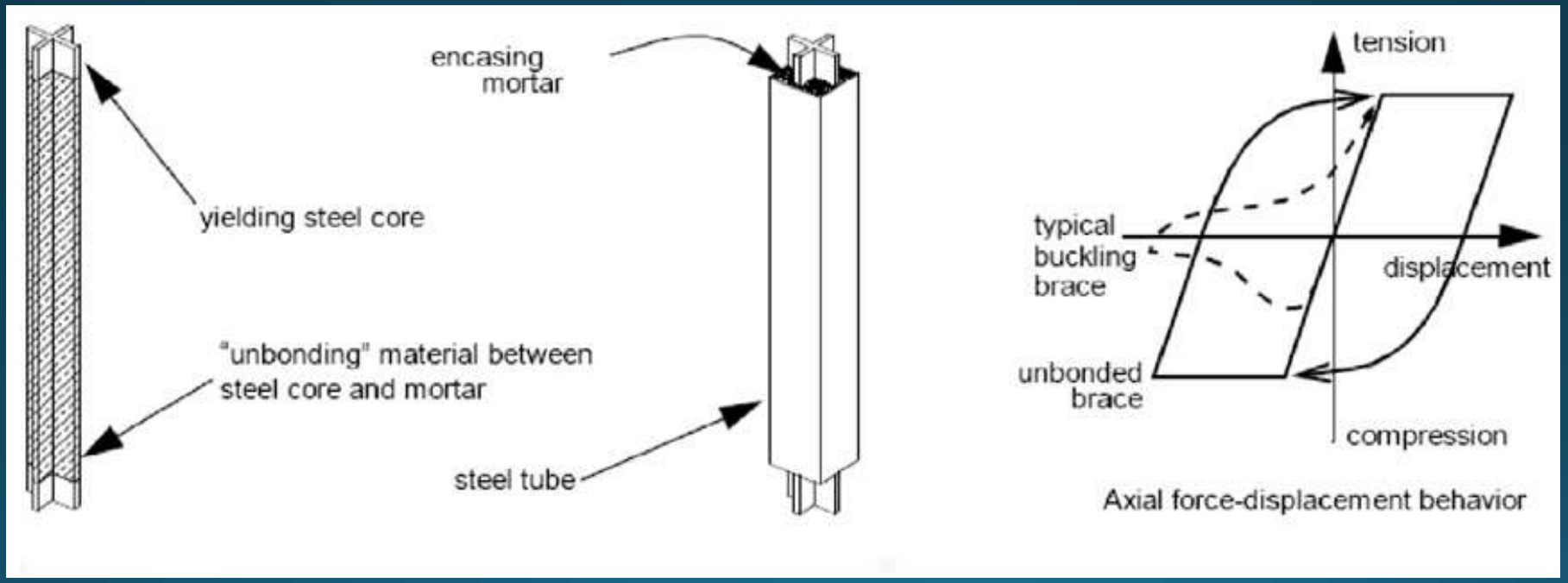


Seismic isolation design method



BRB (Buckling restrained brace)

- In view of the problem above, this paper proposes a new seismic device, TOB (tension-only brace) based on the concept of BRB (buckling-restrained brace).

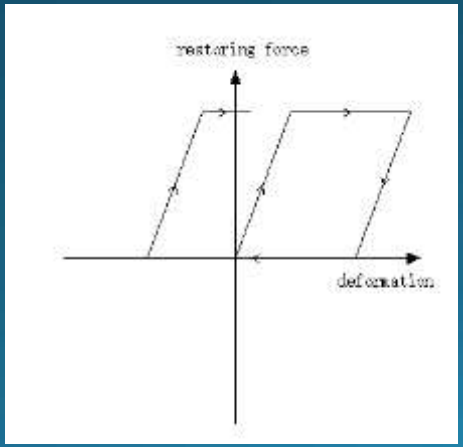


BRB (Buckling restrained brace)

- BRBs have been used in Japan and USA since about 1990. Until now, BRBs are applied mostly in building structures, while less in bridge structures and none in high pier bridges.
- The length of BRB used in buildings is usually less than 10 meters, which is not enough to satisfy the need of bridges especially high pier bridges.
- For high pier bridges, very long BRBs are needed, which may cause the instability problem.
- To avoid lateral buckling under uniaxial loading, BRB introduces a concrete casing.
- How about overall buckling?

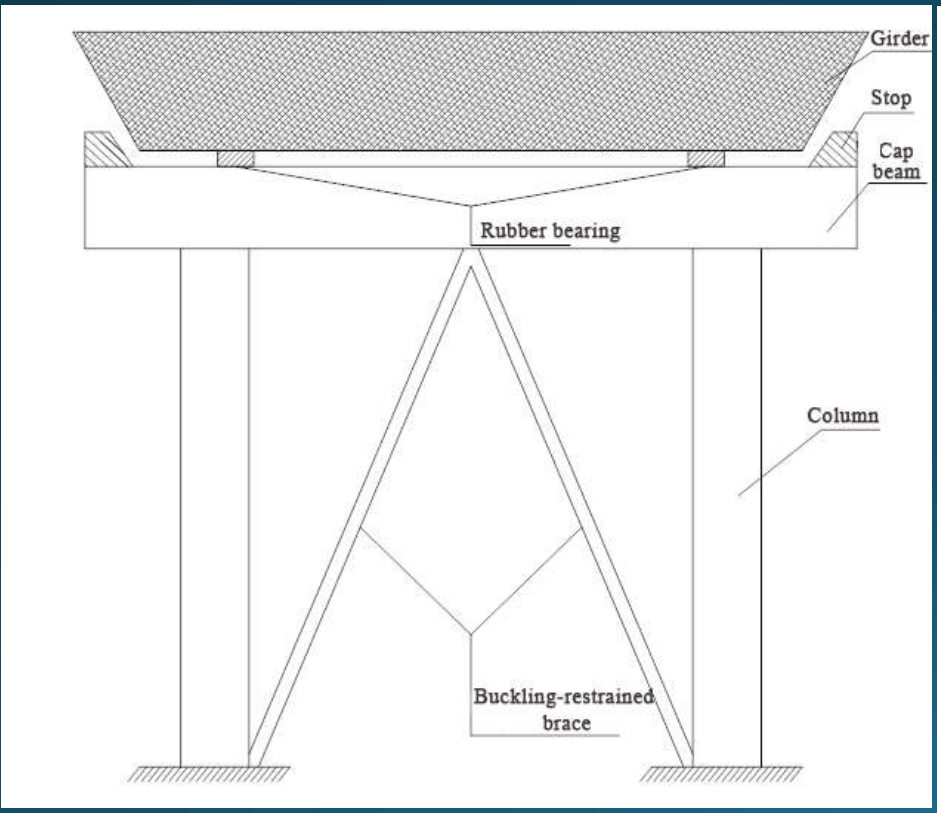
2. Concept development of TOBs

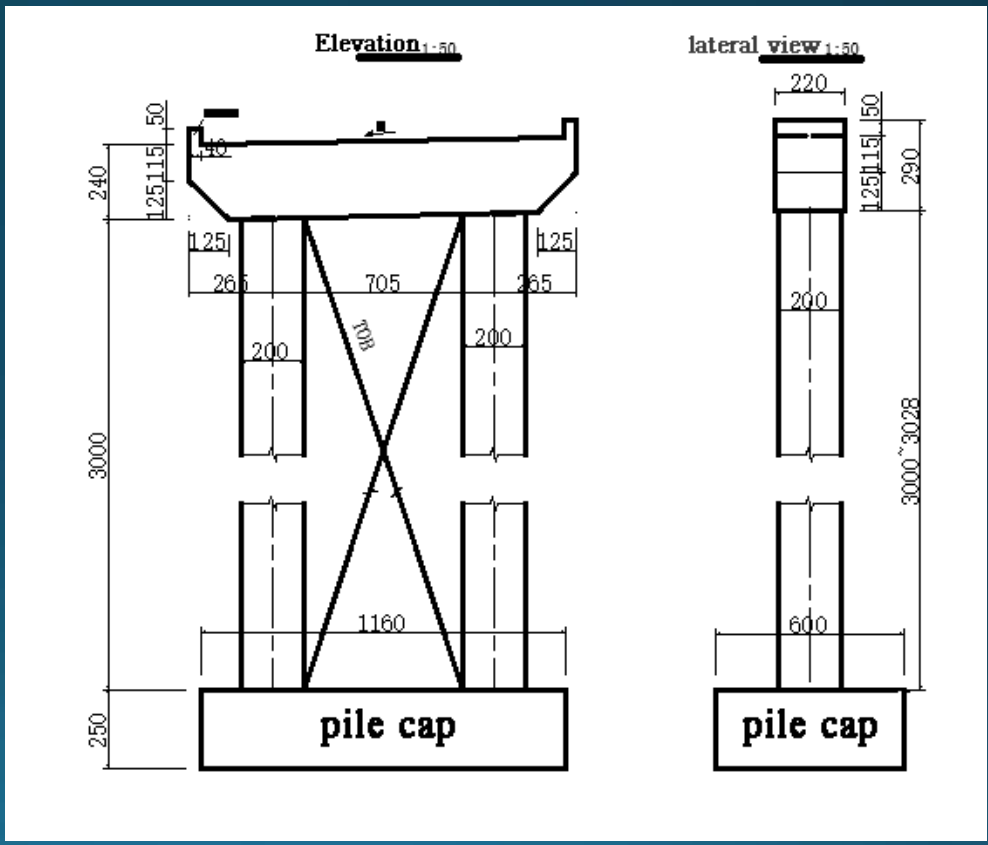
- To address the problem, a tension-only brace (TOB) is proposed.
- TOBs have a similar mechanical behaviors to BRBs under tensile loading, but turns to a zero-stiffness member to avoid buckling when subjected to compressive loading.
- This feature prevents TOBs from local buckling and overall buckling under compressive loading.
- Without the possibility of buckling, TOBs can be designed long enough theoretically and used for high pier bridges.



TOB (tension-only brace)

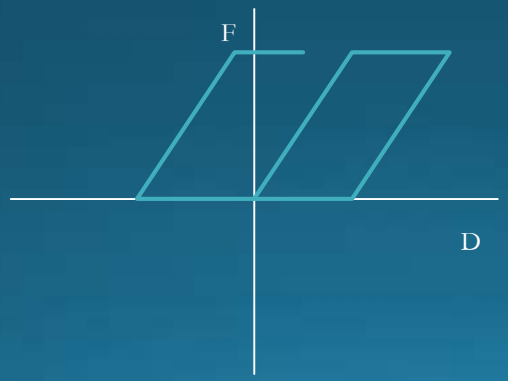
- When used in engineering practice, TOBs can be linked between cap beams and bearing platforms.



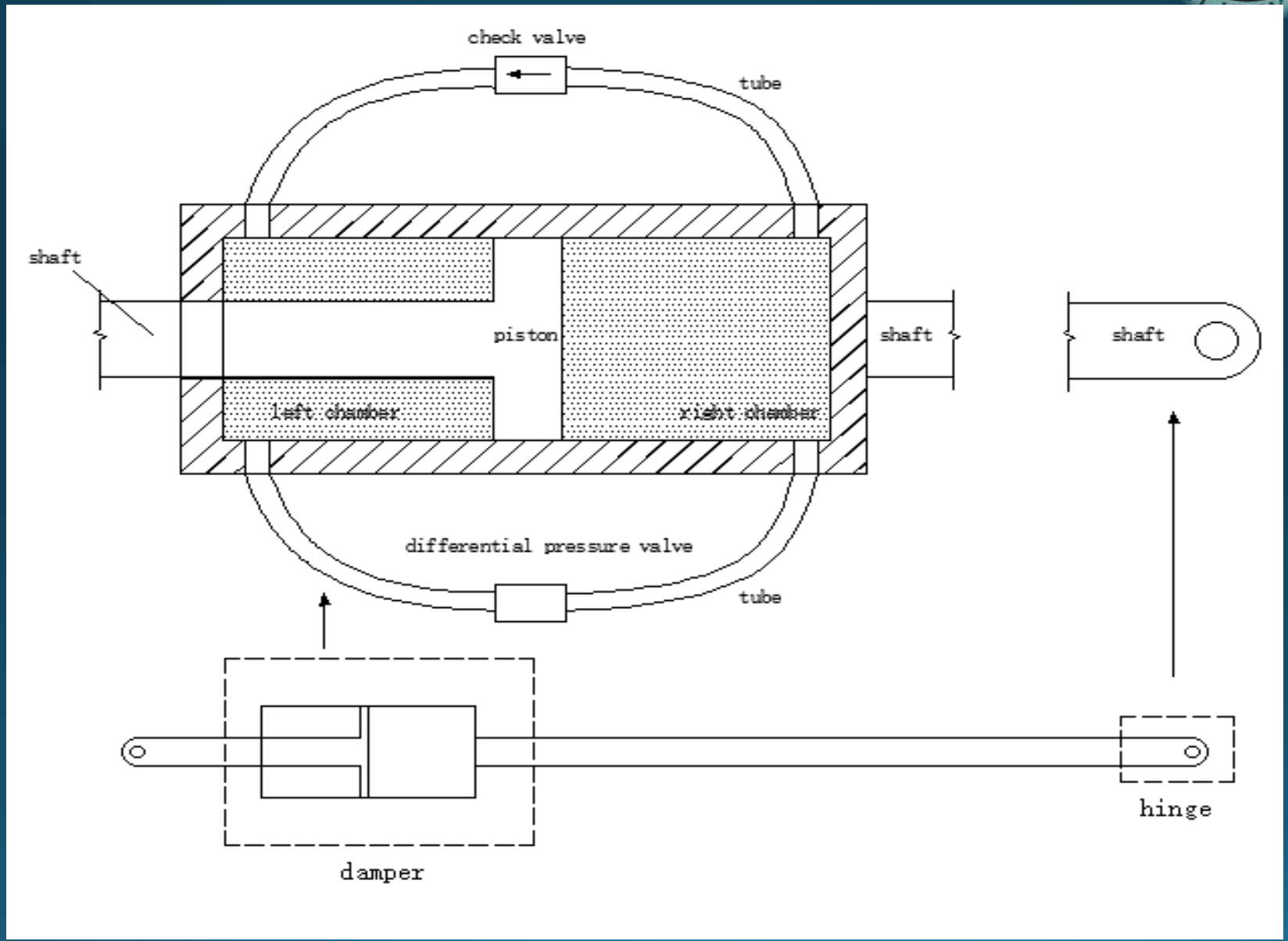


TOB (tension-only brace)

- Advantages of TOB include:
  - TOB would not be subjected to axial compression, so there is no buckling problem;
  - Once the TOB length increases, no matter the current TOB length is larger or less than the original length, the TOB would be subjected to axial tension;
  - Yield force and axial stiffness of a TOB can be designed, and seismic energy can be dissipated partly by the plastic axial deformation of TOBs.

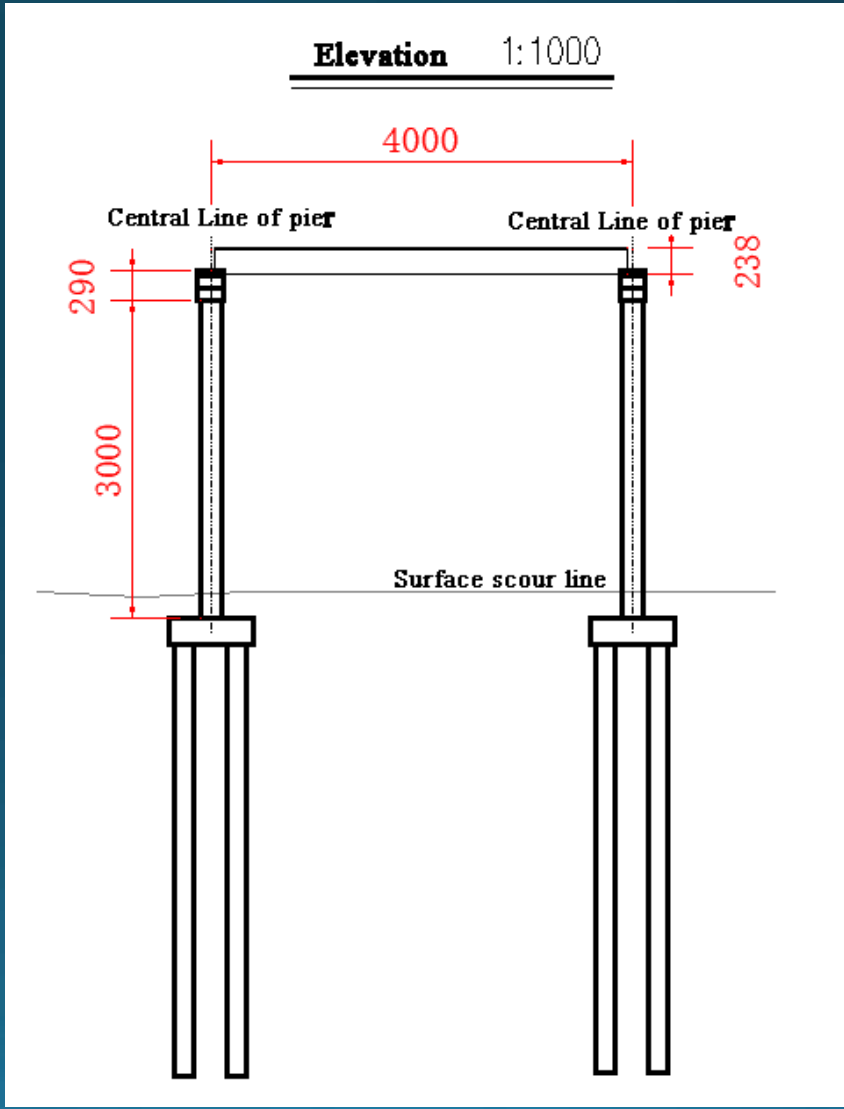


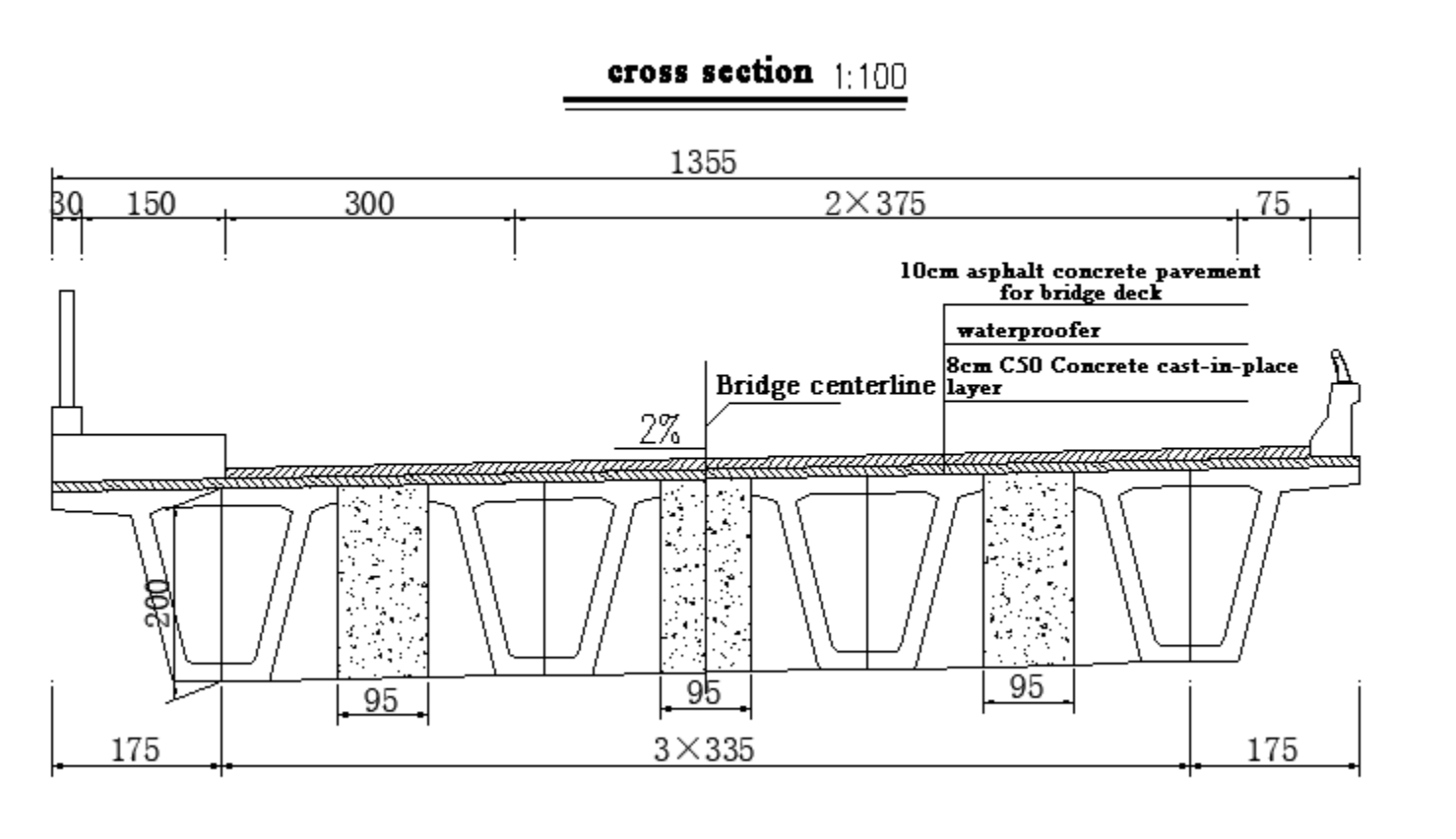
An illustration of a TOB



3. Numerical Simulation Analysis

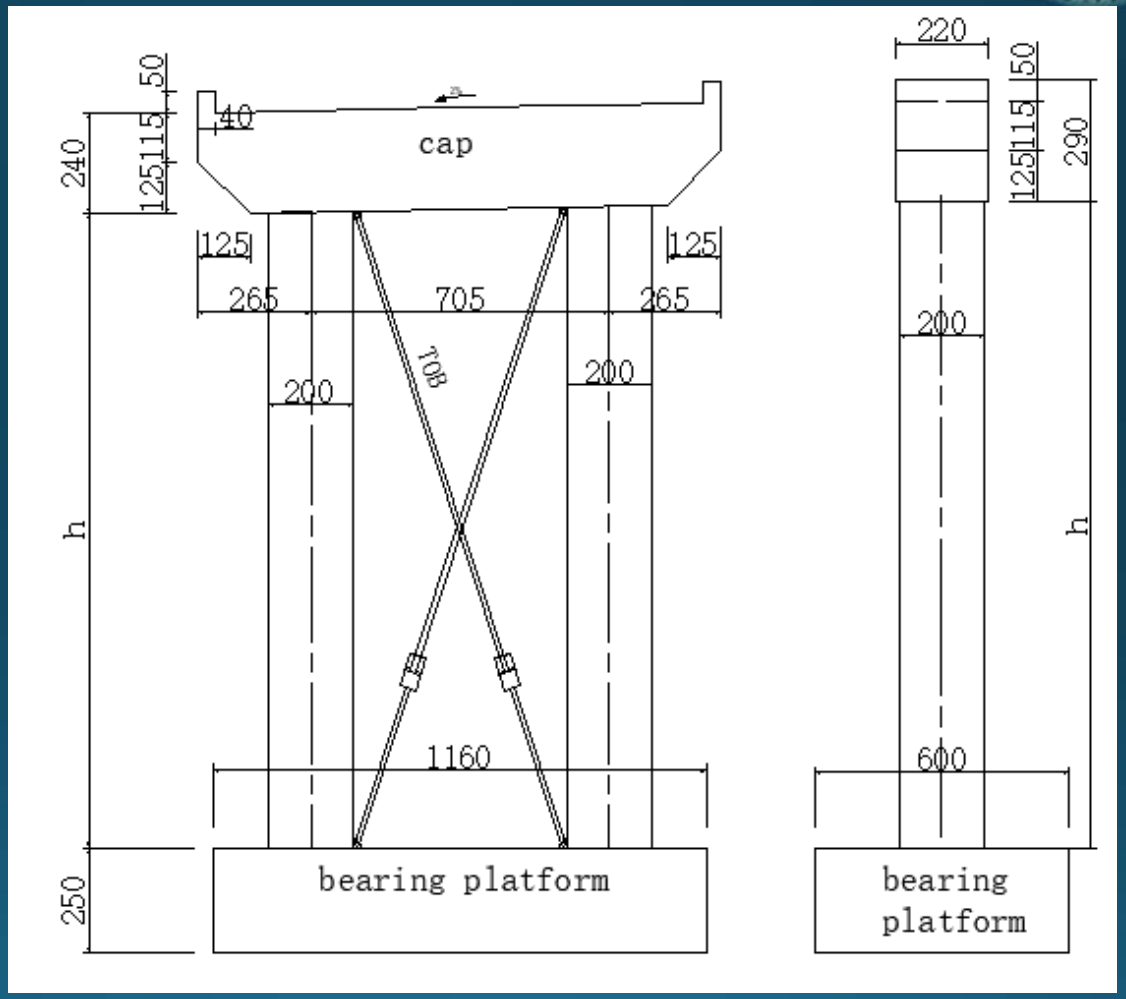
The example is a four-span simply supported bridge with a uniform girder.



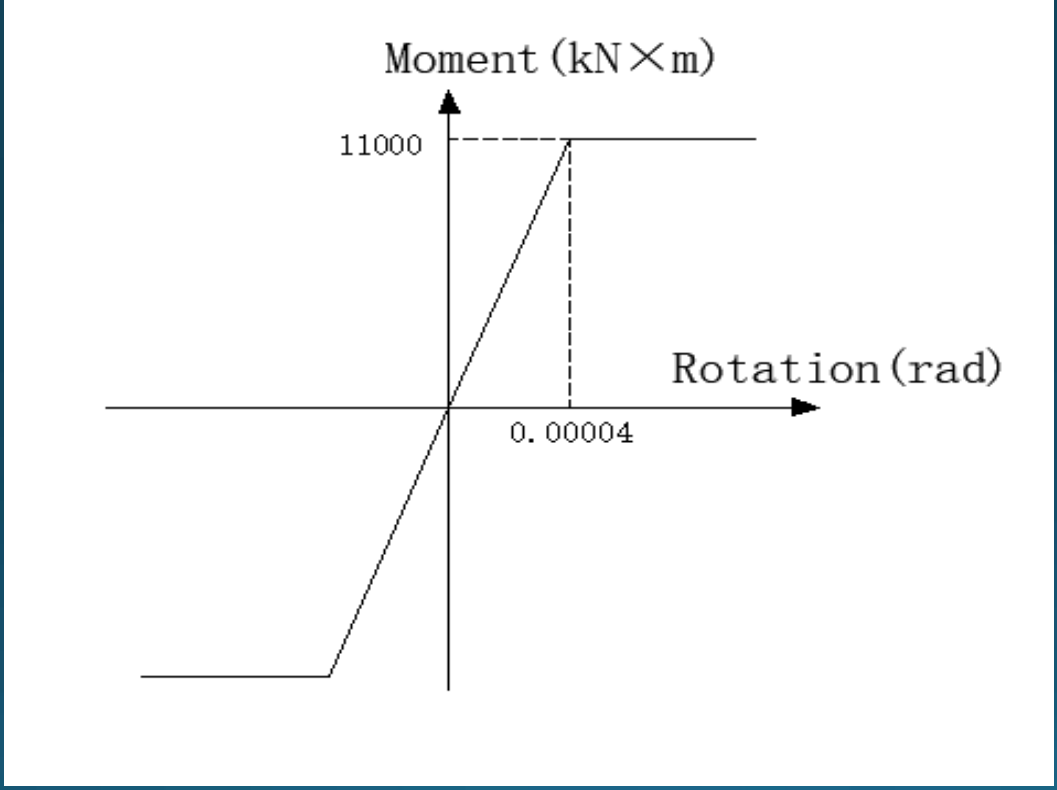


The girder is composed of four small box girders and weighs up to 800 tons

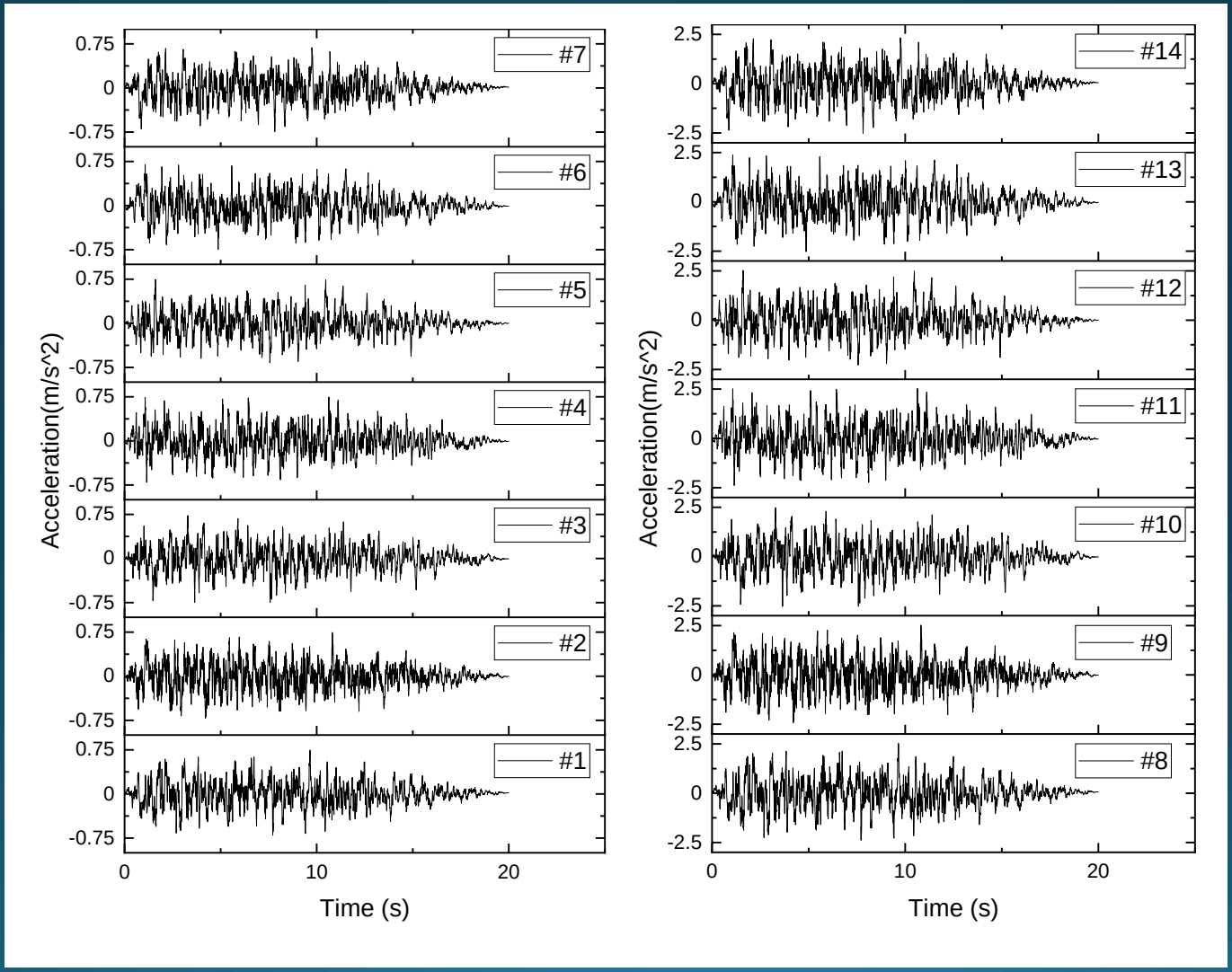
The frame pier is composed of a cap beam and two columns.



Moment-rotation curve for plastic hinges



14 artificial earthquake waves

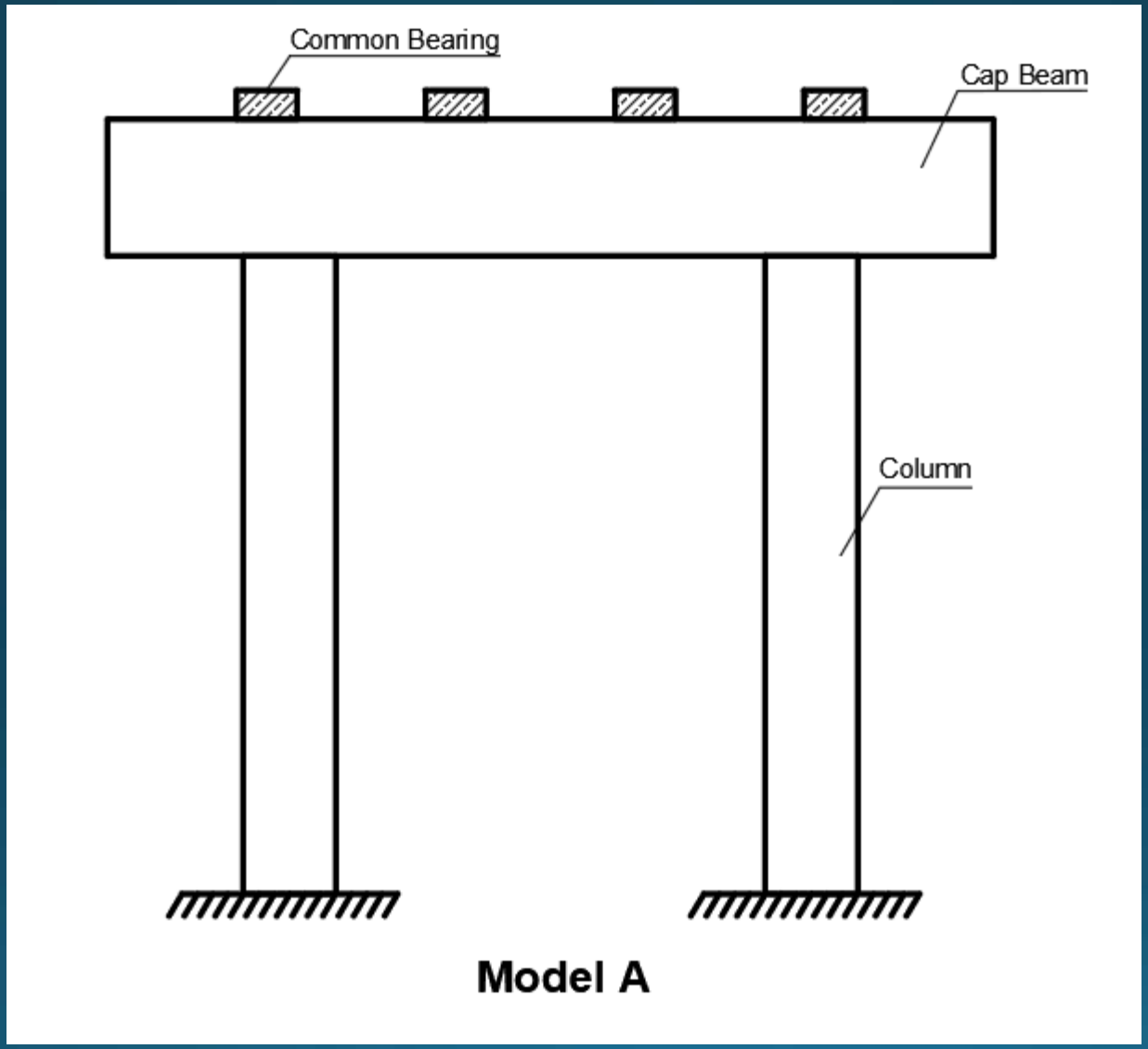


Five Analysis Models

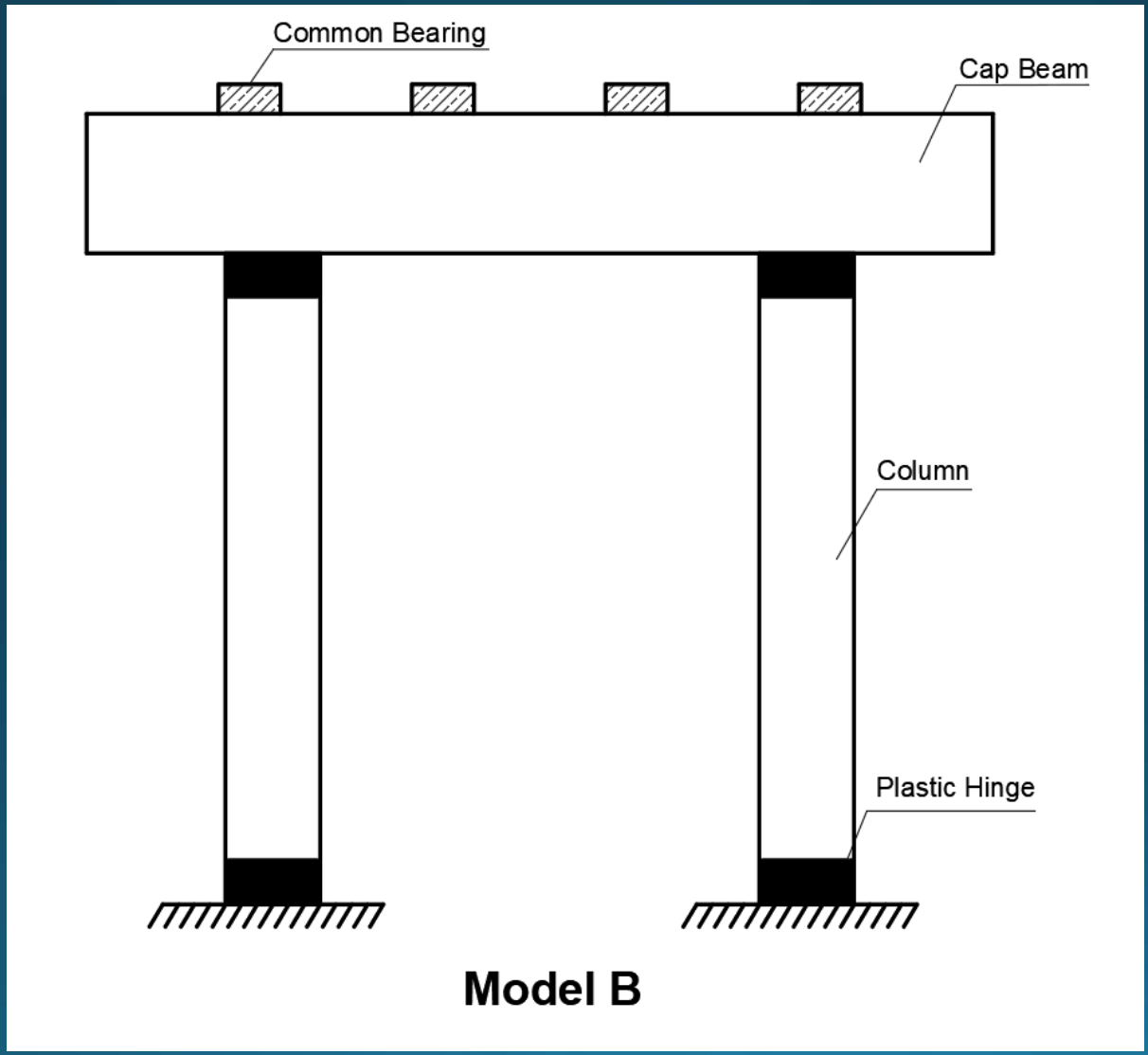
Model	Bearing	TOB	Plastic hinge
A	Common bearing	Without	Without
B	Common bearing	Without	With
C	Lead rubber bearing	Without	Without
D	Common bearing	With	With
E	Lead rubber bearing	With	Without

Five Analysis Models

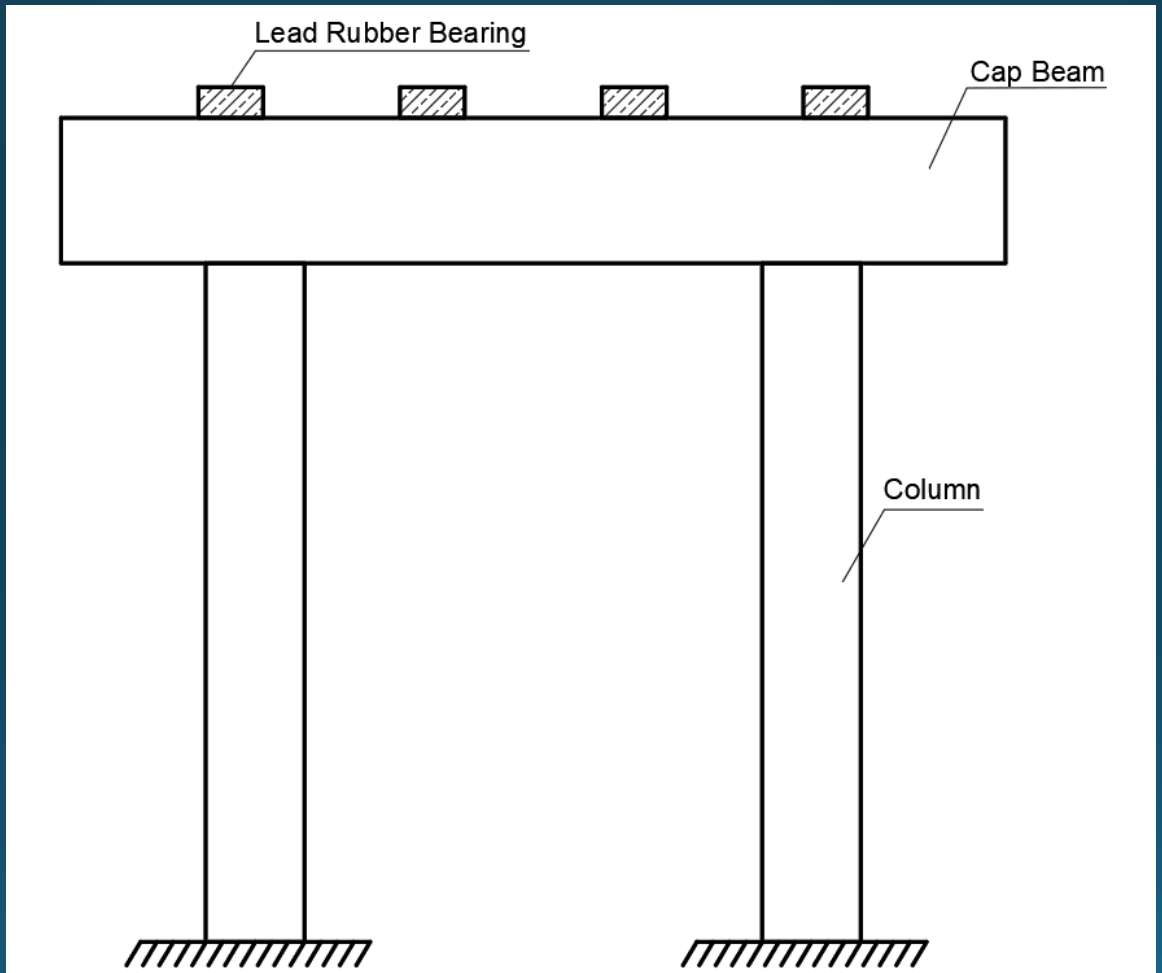
- To compare the ductility design method and seismic isolation seismic design method in high pier bridges, three different models are built.
- To study TOBs' influence on the seismic responses of the bridges, another two models are built.
- Fourteen analysis cases corresponding to 14 artificial waves are set up in each model. The input direction of earthquake is transverse, and damping ratio is set to be 5%.



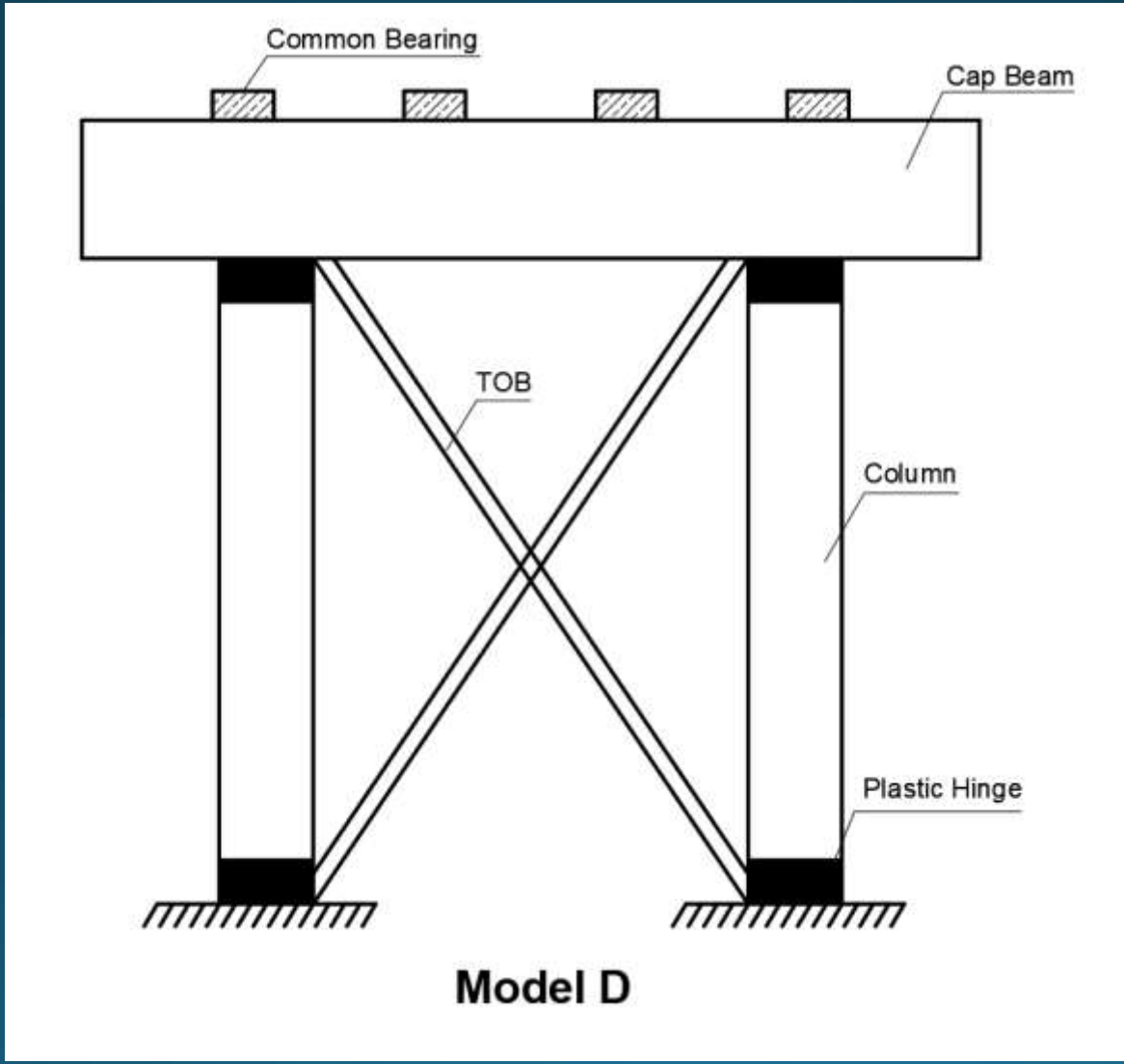
Model A



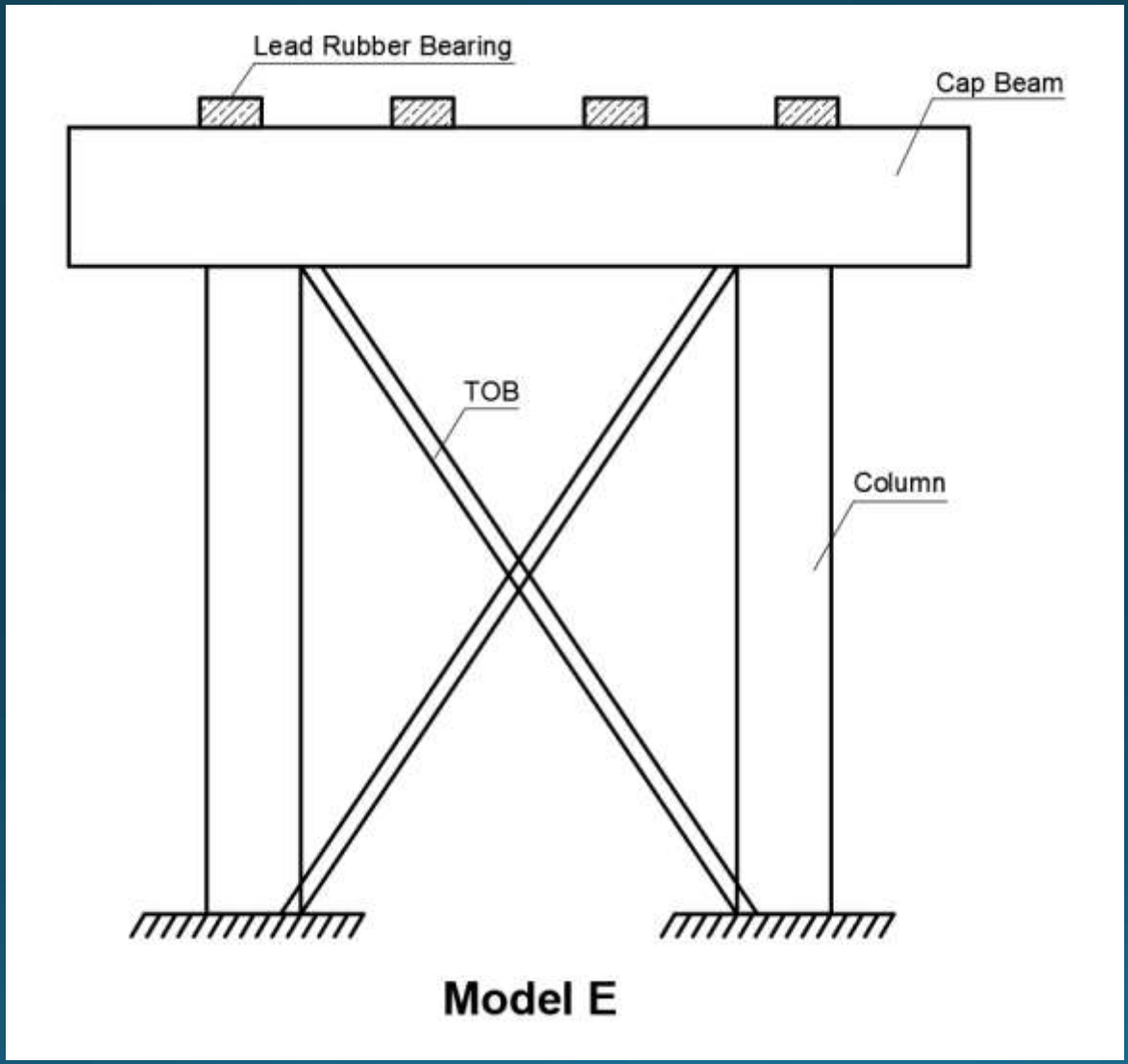
Model B



Model C



Model D


Lead Rubber Bearing
Cap Beam
TOB
Column
Model E

4. Seismic Effect and Mechanism Analysis of TOBs

- Based on the seismic damage investigation of high pier bridges, the bending moment, shear force, rotation at the columns' ends, the lateral displacement of the cap beam are chosen as the key responses to represent the seismic performance of the bridge structure.
- The mean values of 7 maximum values of these key responses during 7 artificial waves are listed.

Model	Displacement of the cap beam /m		Rotation /rad		Bending Moment /kN*m		Shear force /kN	
	E1	E2	E1	E2	E1	E2	E1	E2
A	0.0621	0.2108	1.78E-05	6.06E-04	4832	16414	258	877
B	0.0621	0.1985	1.78E-05	1.60E-03	4832	11050	258	724
C	0.0596	0.1944	1.67E-05	5.51E-05	4515	14933	244	805
D	0.0540	0.1687	1.53E-05	7.07E-04	4145	11030	220	677
E	0.0524	0.1571	1.43E-05	4.48E-05	3889	12139	214	696

The mechanism of TOBs' seismic effect

- The TOB has a certain axial tensile stiffness, and can increase the total lateral stiffness of the bridge structure.
- Then the natural vibration period of the bridge decreases accordingly.
- The fundamental period of most high pier bridges is located in the descending part of the response spectra.
- The decrease of the natural vibration period may result in the increase of input energy under earthquakes.
- So, the change of the total lateral stiffness is not the main reason to change seismic responses.

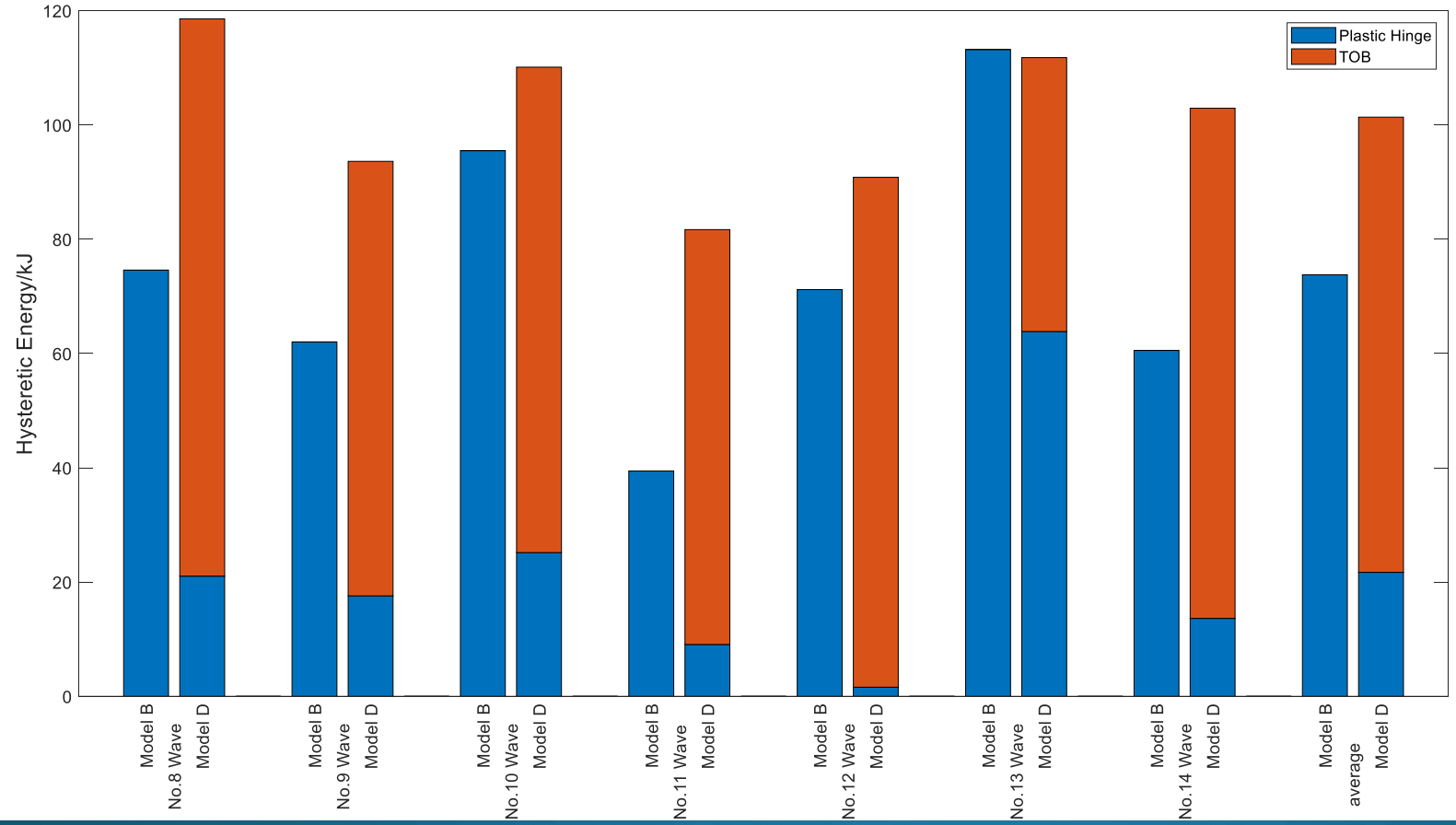
Change the load path

- The introduction of TOBs can change the load path of the inertia force of girders.
- Without TOBs, the inertia force of girders is transferred to the foundation through bearings, the cap beam and columns in sequence.
- The introduction of TOB separates the inertia force on columns into two parts. The first part is still transferred through columns while the second one is transferred through TOBs. As a consequence, the internal force and deformation of piers are reduced.
- However because of the relatively smaller TOBs' axial stiffness compared with the lateral stiffness of piers, the seismic effect of changing load path is very limited.

The ability to dissipate energy

- According to the numerical simulation results, the accumulative hysteretic energy of the whole bridge structure is substantially increased after the introduction of TOBs.
- The average increase of 7 artificial earthquake waves under E2 earthquake actions is up to 37.4%.
- TOBs provide a new device for high pier bridges to dissipate seismic energy.
- TOBs can accelerate the process of energy dissipation during earthquakes and protect the whole bridge structure from accumulating too much energy that may lead to the collapse of bridges.
- And this is the most important reason on the seismic mechanism of TOBs.

Accumulative hysteretic energy



5. Conclusions

- A check valve and a differential pressure valve are used to develop a new seismic device TOB. TOBs have a similar mechanical behaviors to BRBs under tensile loading, but turns to a zero-stiffness member to avoid buckling when subjected to compressive loading.
- TOBs can reduce displacements and internal forces of high pier bridges under both E1 and E2 earthquake actions. Therefore, the cost of post-earthquake rehabilitation for high pier bridges is reduced accordingly.
- The introduction of TOB changes the lateral stiffness, load path and energy dissipation of high pier bridges. Among them, the change of energy dissipation is the dominant one.

Thanks for your attention!