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Comparative Assessment of Seismic Collapse Risk for Non-ductile and Ductile Bridges

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Outline

- Introduction
- Proposition and verification of numerical models for bridge columns
- Seismic hazard model
- Seismic fragility model
- Seismic risk assessment of bridge structures
- Case study
- Conclusion

1. Introduction

- Previous studies have shown that seismic performance of RC girder bridges are influenced by the ductility during earthquakes.
- How to establish collapse fragility model regarding different collapse criteria for the RC girder bridges with and without ductile detailing.
- According to the seismic hazard curve in a specific area, a comprehensive study of ductile and non-ductile bridges is conducted to determine whether the existing RC bridges have sufficient seismic capacity.

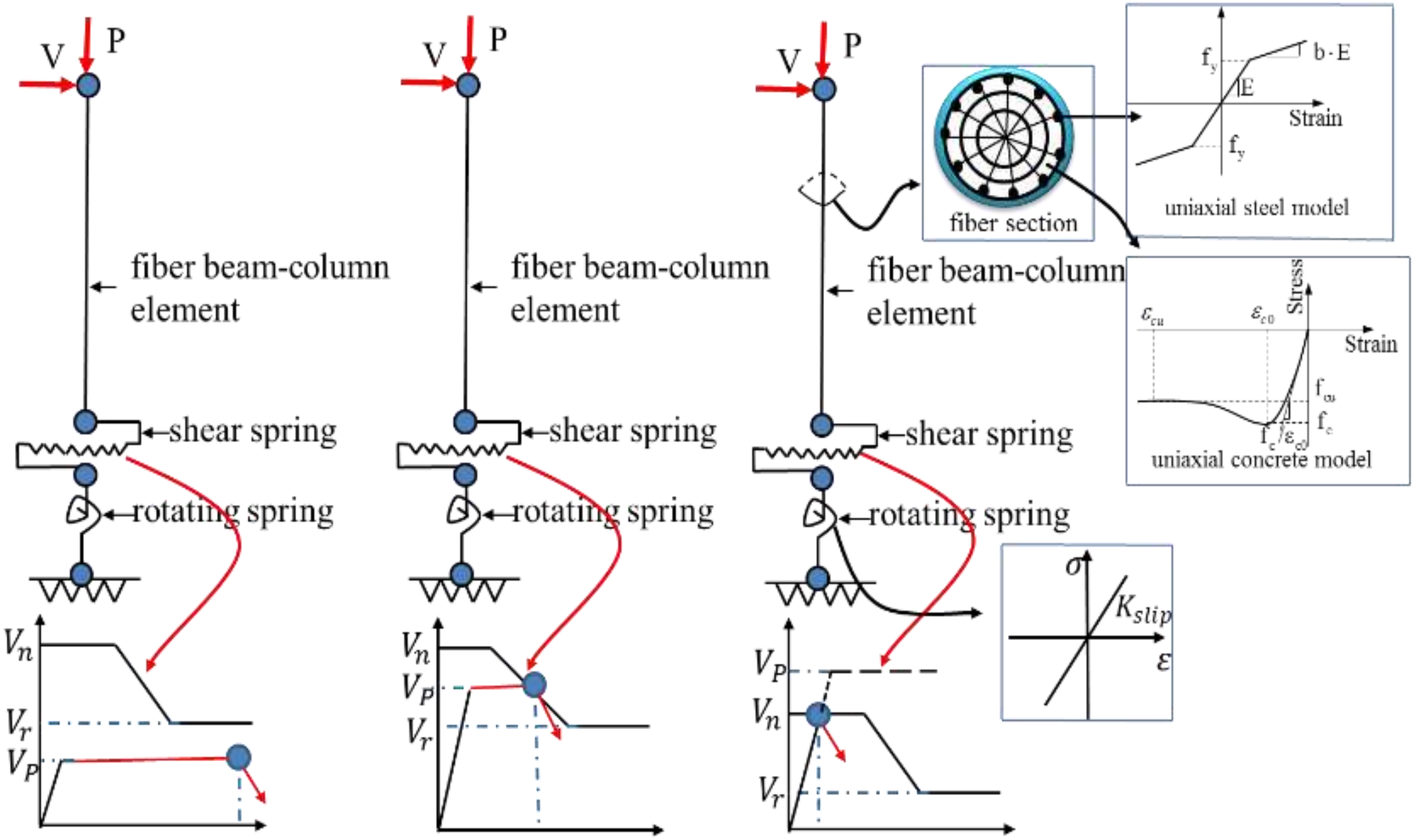
2. Proposition and verification of numerical models for bridge columns

2.1. Prediction of failure modes

Transverse Reinforcement Details	**ACI conforming details with 135° hooks**	**Closed hoops with 90° hooks**	**Other (including lap spliced transverse reinforcement**
$V_p / V_n \le 0.6$	flexure failure	flexure-shear failure	flexure-shear failure
$0.6 < V_p / V_n \le 1$	flexure-shear failure	flexure-shear failure	shear failure
$V_p / V_n > 1$	shear failure	shear failure	shear failure

American Society of Civil Engineers (ASCE/SEI 41–06). Seismic rehabilitation of existing buildings. *American Society of Civil Engineers*: Reston, Virginia, 2013.

2.2 The finite element model of bridge

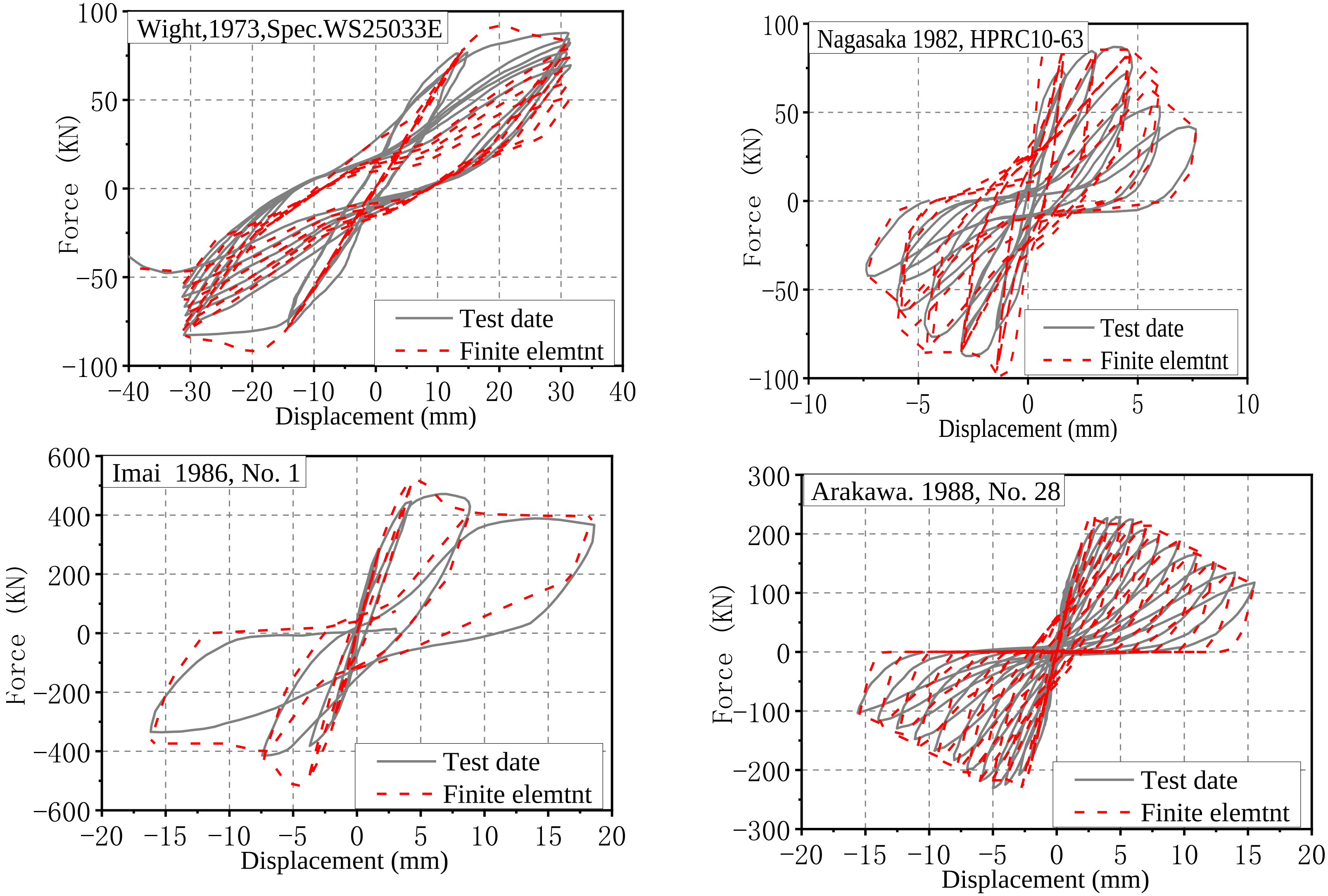


(a) Flexural failure (b) Flexural-shear failure (c) Shear failure

Fig.2 – The finite element model corresponding to various failure modes

ELWOOD K J. Modelling failures in existing reinforced concrete columns. *Canadian Journal of Civil Engineering*, 2004, 31(5):846-859.

2.3 Verification of different failure models



(a) Shear failure

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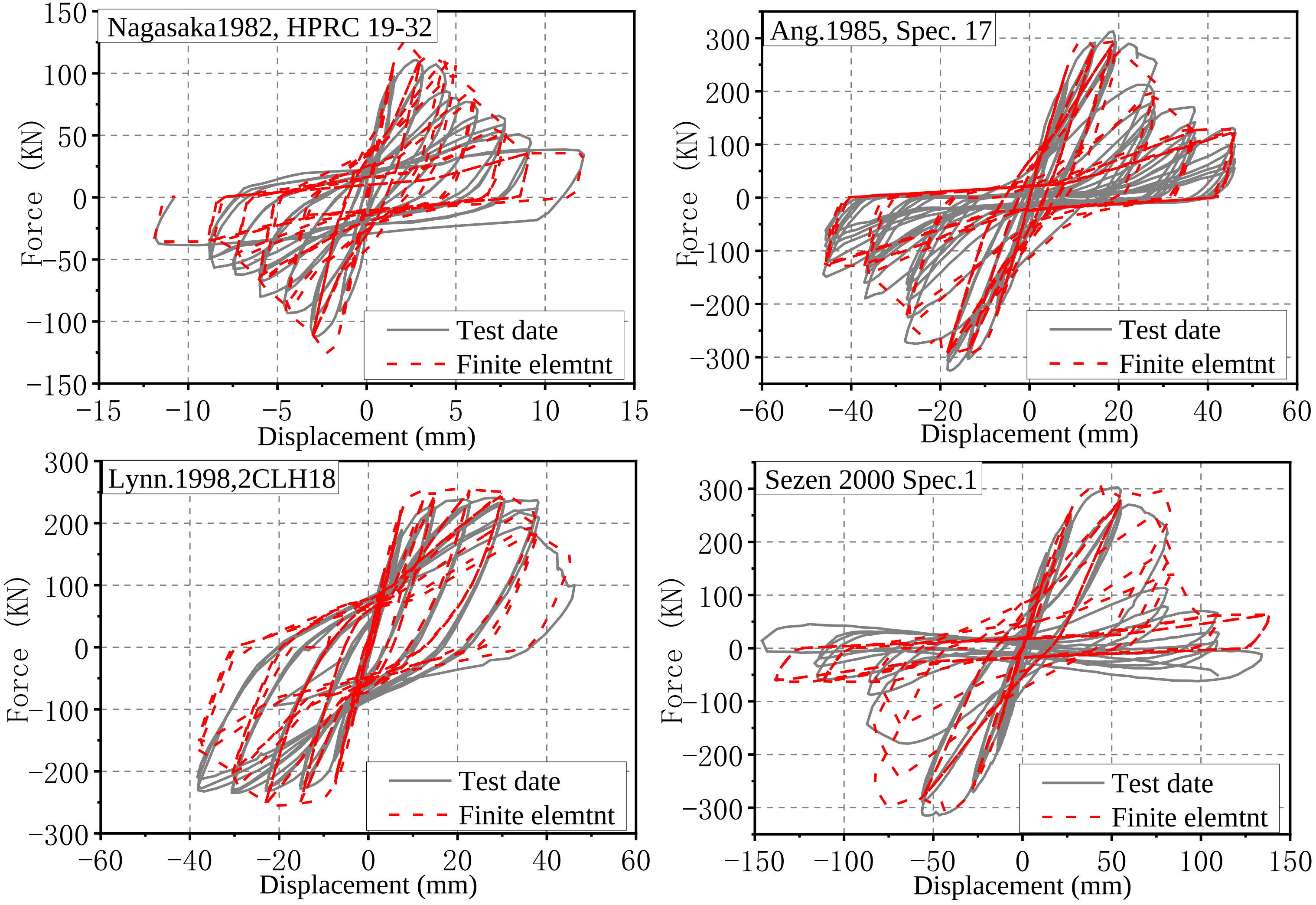
2.3 Verification of different failure models



(b) Flexure–shear failure

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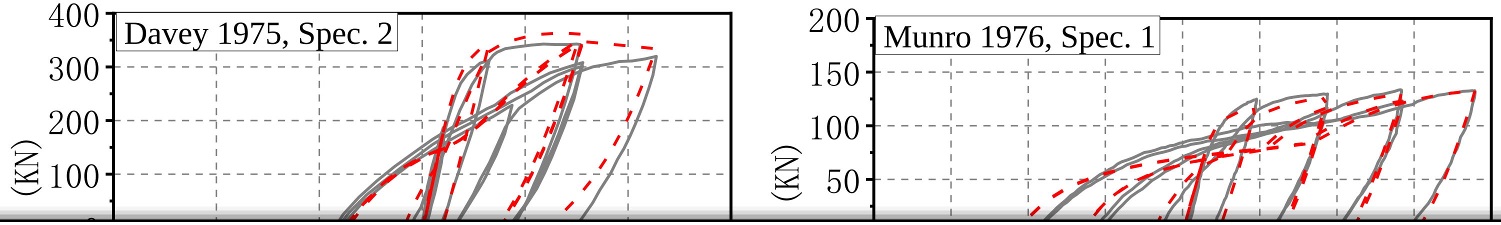
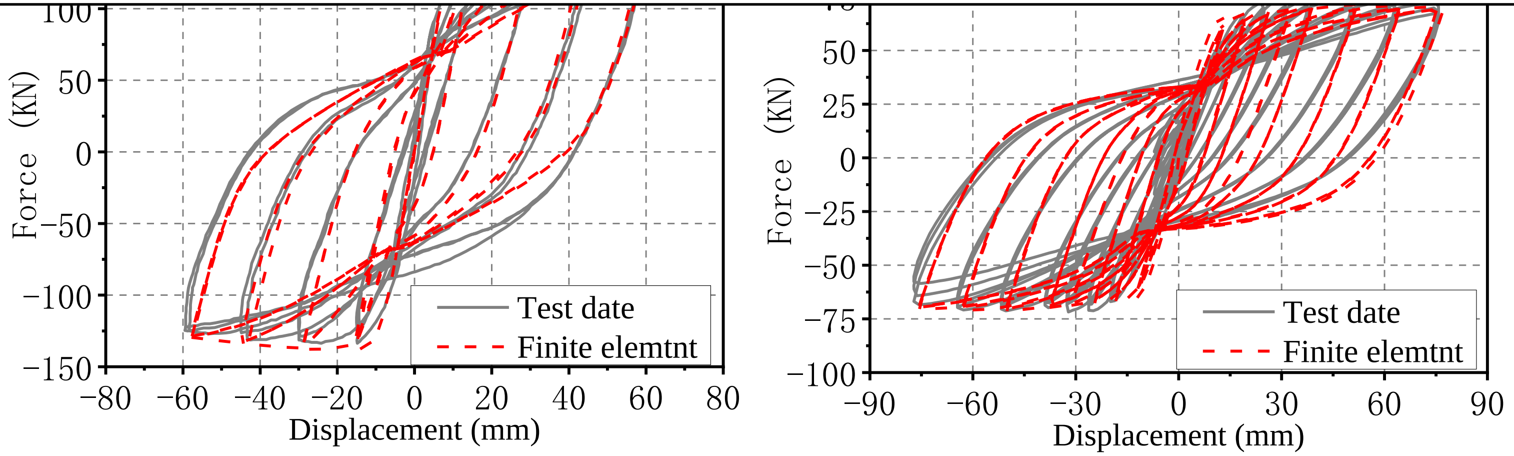
2.3 Verification of different failure models



The finite element model can accurately simulate the initial stiffness, shear failure point, strength degradation slope and residual shear strength of the structure.



(c) Flexure failure

- **Step 1: seismic hazard model**

$$H(a) = P\left[A \geq a\right]$$

$$H(a) = P\left[PGA \geq a\right] = \nu(IM) = k_0 (IM)^{-k}$$

$$\begin{cases} k = \dfrac{\ln(\nu_{DBE} / \nu_{MCE})}{\ln(IM_{DBE} / IM_{MCE})} \\[2ex] \ln(k_0) = \dfrac{\ln(IM_{DBE}) \cdot \ln(\nu_{MCE}) - \ln(IM_{MCE}) \cdot \ln(\nu_{DBE})}{\ln(IM_{DBE} / IM_{MCE})} \\[2ex] \left| \dfrac{dH(a)}{d(IM)} \right| = k_0 k (IM)^{-(k+1)} \end{cases}$$

LIEL A B. Assessing the collapse risk of California's existing reinforced concrete frame structures: metrics for seismic safety decisions. *California: Stanford University*, 2008.

$$H(a)=\nu(IM)=8.9\times10^{-6}(IM)^{-2.33}$$

$$\left|\frac{dH(a)}{d(IM)}\right|=8.9\times10^{-6}\times2.33(IM)^{-3.33}$$

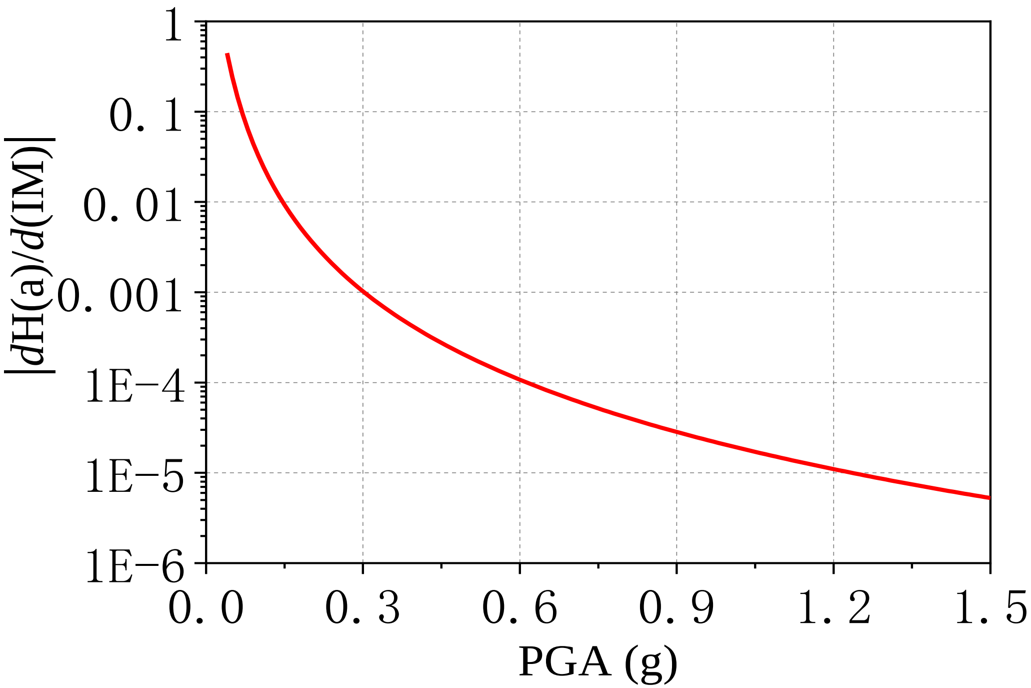


Fig.8– Curve of the seismic hazard

• Step 2: seismic fragility model of bridge structure

$$P_i\left[D \ge C \middle| IM\right] = \Phi\left[\frac{\ln(IM)-\ln(m)}{\beta}\right]$$

The seismic fragility analysis is to find the probability of a structure reaching or exceeding a certain state of damage under a given GM intensity.

ZAKERI B, PADGETT J E, AMIRI G G. Fragility analysis of skewed single-frame concrete box-girder bridges. *Journal of Performance of Constructed Facilities*, 2014, 28(3):571-582.

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• Step 3: seismic risk assessment of bridge structures

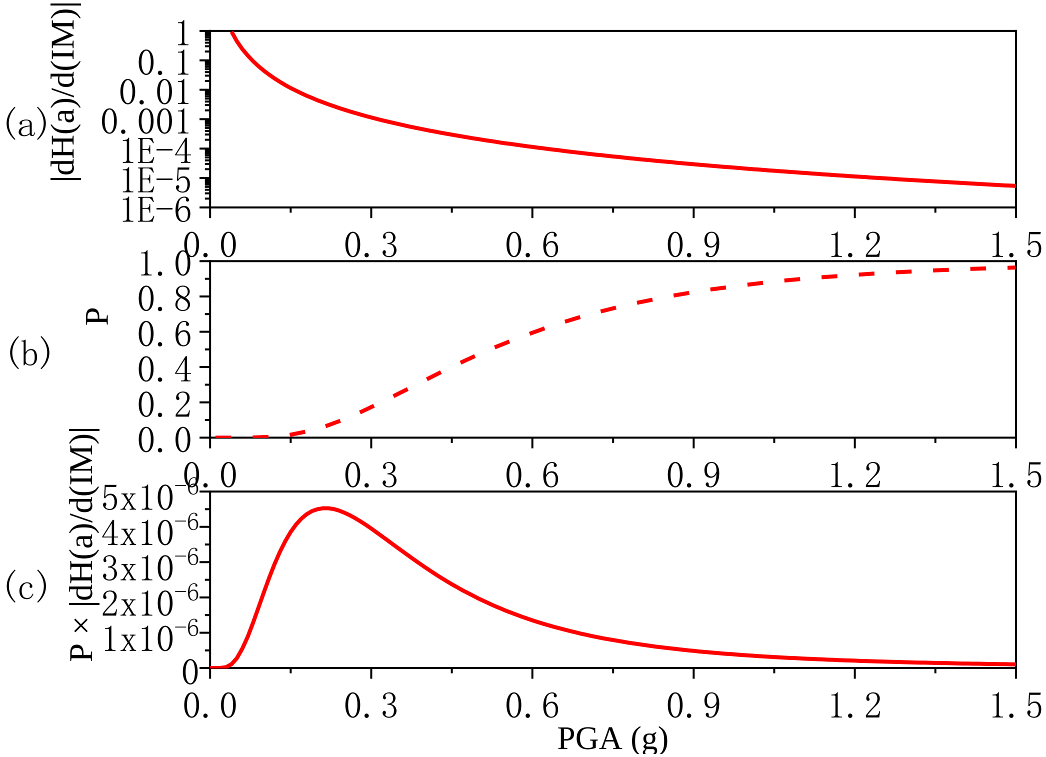


Fig.1 – The process of seismic risk assessment

$$v_c=\int P(IM)\cdot\left|\frac{dH(a)}{d(IM)}\right|d(IM)=\sum_{0}^{\infty}P(IM)\cdot\left|\frac{dH(a)}{d(IM)}\right|\Delta(IM)$$

EADS1 L, MIRANDA E, KRAWINKLER H, et al. An efficient method for estimating the collapse risk of structures in seismic regions. *earthquake engineering & structural dynamics*,2013, 42:25–41.

4.1 Design details and simulation of bridge

(1) Numerical models of three-span simply supported girder bridge

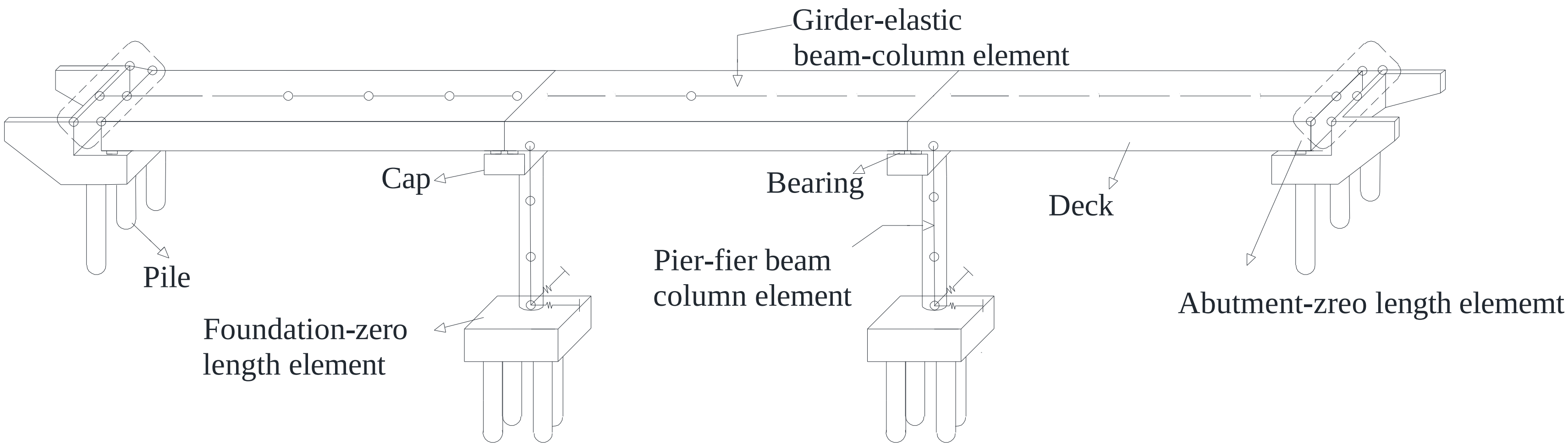


Fig.4 – Configuration details of the designed bridge

CHEN Libo. Seismic fragility analysis for highway bridges in Wenchuan region. *Southwest Jiaotong University*,2012. (in Chinese)

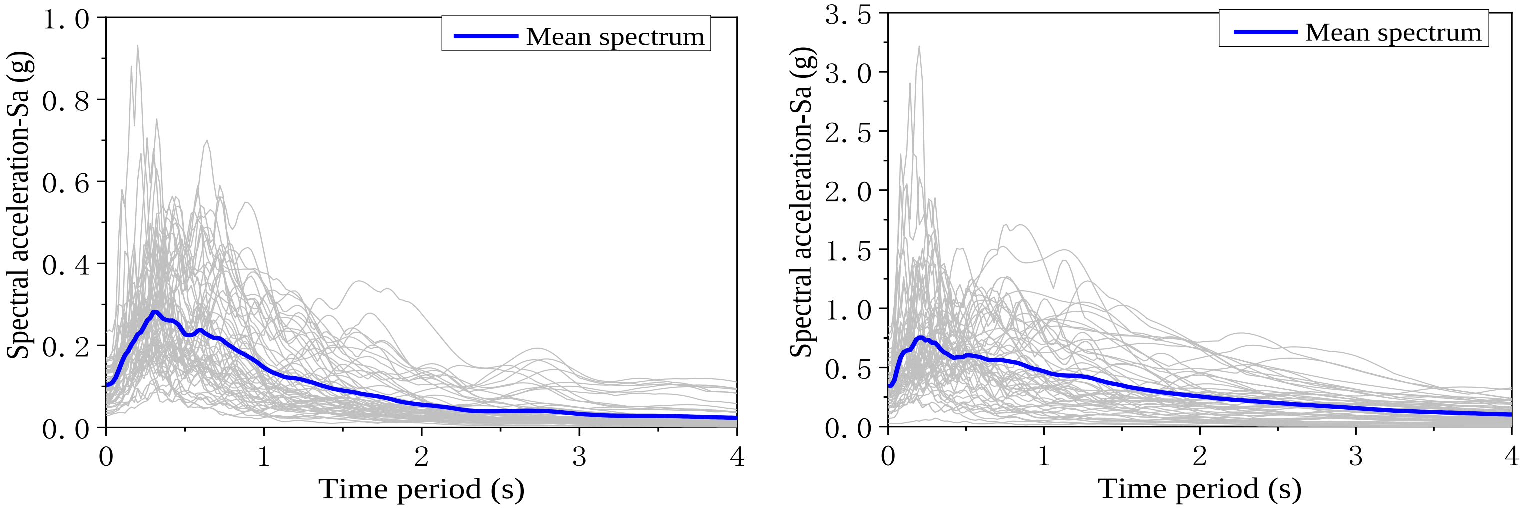
(2) Uncertainty of structural parameters

Table 3 – Structural parameters and Distributions Incorporated in the Bridge Model

Parameter	Distribution type	Distribution parameter	
		P1	P2
Concrete strength (MPa)	Normal distribution	25(35)	4.5(4.5)
Shear elastic modulus of bearing(MPa)		1.18	0.16
Damping ratio		0.045	0.0125
expansion joint width (mm)		40	4
Longitudinal reinforcement ratio	uniform distribution	0.4%(1.0%)	1.0%(2.2%)
Transverse reinforcement ratio		0.1%(0.4%)	0.3%(1.2%)
Concrete density		0.9	1.1
Abutment initial stiffness (kN/mm/m)		11.5	28.5
Proportional coefficient of foundation horizontal resistance (kN/m^4)		60000	100000
Longitudinal reinforcement yield strength (MPa)	Lognormal distribution	5.7(5.8)	0.1(0.1)
Transverse reinforcement yield strength (MPa)		5.5(5.7)	0.1(0.1)

Note: The value in bracket of Table 3 is from the ductile girder bridge.

(3) Selection of ground motion



(a)Response spectra of far-field ground motions (b) Response spectra of near-field ground motions

Fig.5 – Response spectrum of ground motions

Sixty near-fault records and sixty far-field records were selected from the (PEER) Ground Motion Database and the European Ground Motion Database.

4.2 Collapse fragility analyses of bridge system

(1) Collapse performance assessment procedure

The sideway and vertical collapse of the pier or the relative displacement of girder exceeds support length are defined as the collapse criteria of the bridge.

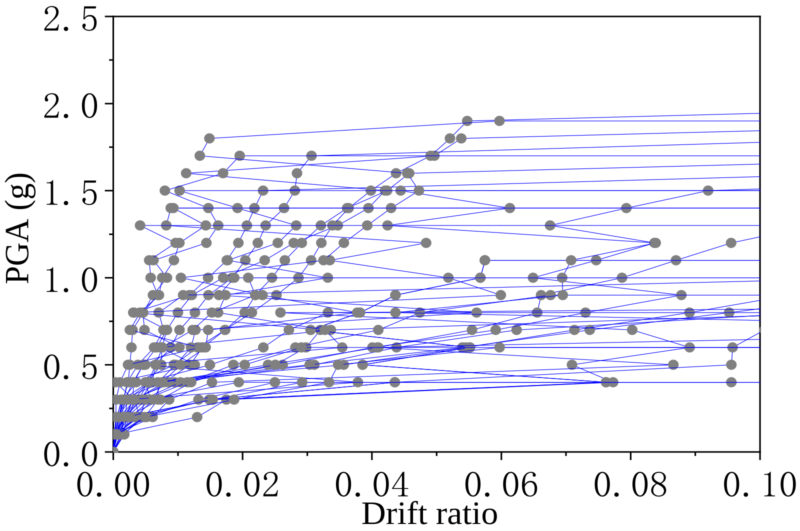


Fig.6 – IDA curves

$$\Delta / L = 0.184\exp(-1.45\mu)$$

$$\mu = \frac{\dfrac{P}{A_{st} f_{yt} d_c / s} - 1}{\dfrac{P}{A_{st} f_{yt} d_c / s}\dfrac{1}{\tan\alpha} + \tan\alpha}$$

ZHU L, ELWOOD K J, HAUKAAS T. Classification and seismic safety evaluation of existing reinforced concrete columns. *Journal of Structural Engineering*, 2007, 133(9): 1316-1330.

(2) Seismic fragility analysis of bridge system

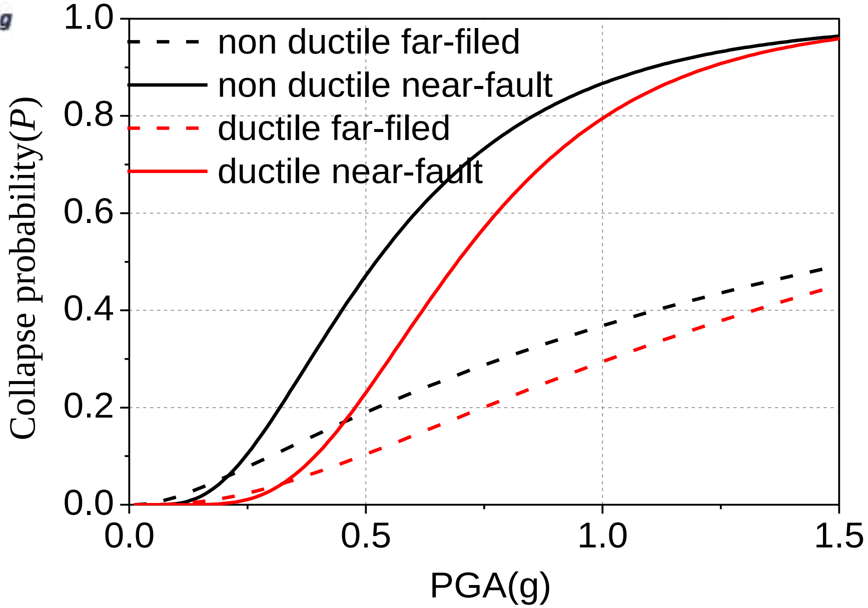
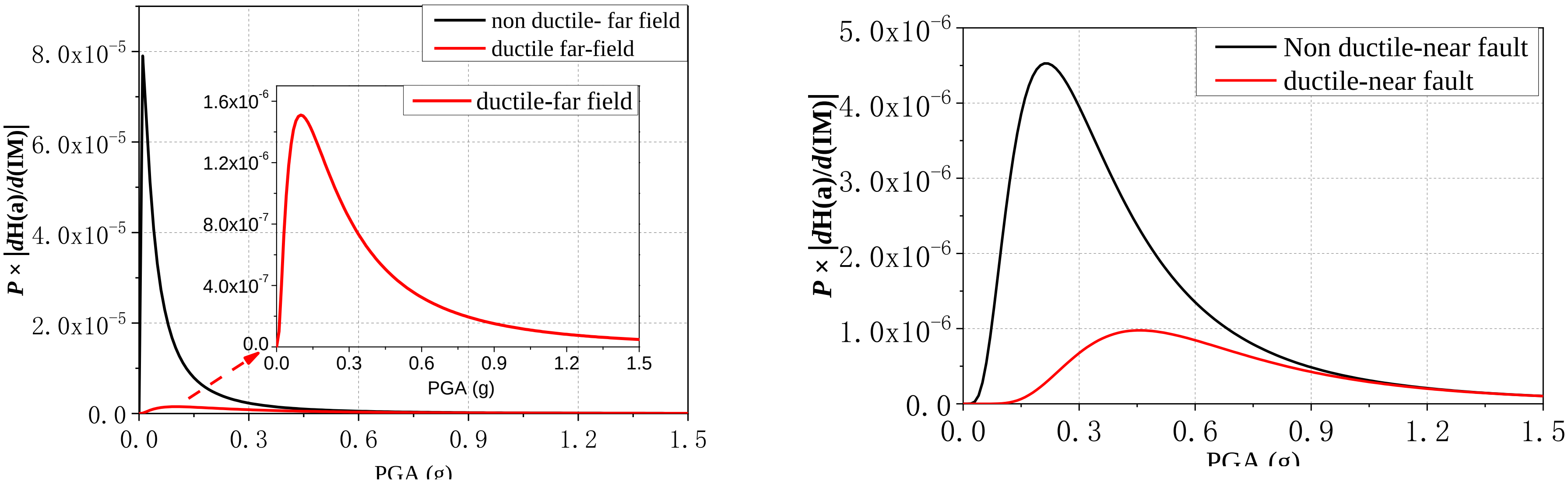


Fig.7 – Collapse fragility curve of the bridges

Table 4 – Fragility model parameters for non-ductile and ductile bridges

Parameter	Non-ductile Far field	Non-ductile near fault	Ductile far field	Ductile near fault
Median value m	1.54	0.52	1.68	0.69
Logarithmic standard deviation β	1.28	0.59	0.96	0.44



(a) Collapse deaggregation plot under far-field ground motions

(b) Collapse deaggregation plot under near-fault ground motions

Fig.9 – Seismic collapse deaggregation plot of the bridge

$$v_c = H(m)\exp(1/2k^2\beta^2)$$

Table 5 – Mean annual collapse probability of bridge

Mean annual collapse probability	Non-ductile far field	Ductile far field	Non-ductile near field	Ductile near field
v_c	2.78×10^{-4}	3.24×10^{-5}	1.05×10^{-4}	3.57×10^{-5}

5. Conclusions

- The finite element models of the pier columns are established and compared with the experimental data of flexure failure, flexure-shear failure and shear failure. The numerical model provide acceptable accurate solution on simulating the static response of its three failure modes.
- The structural collapse deaggregation is not only related to the collapse probability of the structure under certain ground motion intensity, but also to the occurring probability of the ground motion intensity exceeding a given threshold.
- The mean annual collapse frequency of ductile girder bridges is smaller than that of non-ductile girder bridges. The seismic behavior and seismic collapse safety of bridges could be improved with ductile detailing.

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Thanks for listening!