RailAdapt Workshops

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Building a resilient railway

Characteristics of Pounding at Beam End under Strong Earthquake and Unseating Prevention Study of HSR Simply-Supported Beam Bridge

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INTRODUCTION

The problem: unseating disaster of simply-supported beam bridge (SSB) caused by seismic actions has become a potential threat to the safety operation of high-speed railway in China and other countries especially in high intensity seismic region. Such type of disaster is usually accompanied by pounding at beam end. Design method for unseating prevention and countermeasures were studied by researchers (Megally et al., 2001; Kehai Wang, 2015; Bin Yan et al., 2013; Yan Shi, 2011; Xingchong Chen et al., 2016).

DEVELOPMENT OF PC SSB BRIDGE OF HSR IN CHINA

Bridge has a higher occupation ratio in HSR of China with an average value of 47.9% in length. And prestressed concrete SSB bridge with ordinary span accounted for more than 90 percent in total length of bridge. A systematic construction technology of manufacturing, transportation and erection for precasted SSB bridge has been applied as shown in Fig. 1.

Fig. 1 Construction technology of HSR SSB bridge in China

CHARACTERISTICS OF POUNDING AT BEAM END

A detailed FEM model was proposed for HSR SSB bridge with span of 4×31.5m (Fig. 1). To analyze the characteristics of pounding at beam end, seismic waves were artificially fitted (SW1 to SW3)and selected from PEER website (SW4 to SW6) as shown in Fig.3. And four bridge models labeled from Model 1 to Model 4 with pier height 10m, 10m, 20m, 20m respectively. During the analysis, the fixed bearings of model 1 and 3 were assumed to be in failure and the friction between beam and bearing was considered. Bearings of model 2 and 4 were in good condition. The gap between beam end was 100mm.

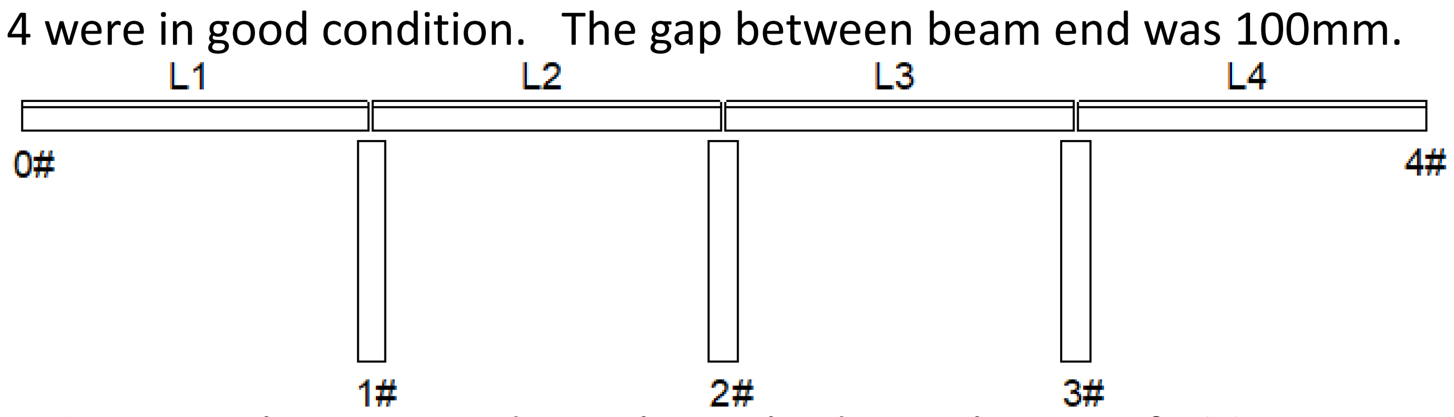

Fig. 1 Simply-supported HSR beam bridge with span of 4×31.5m

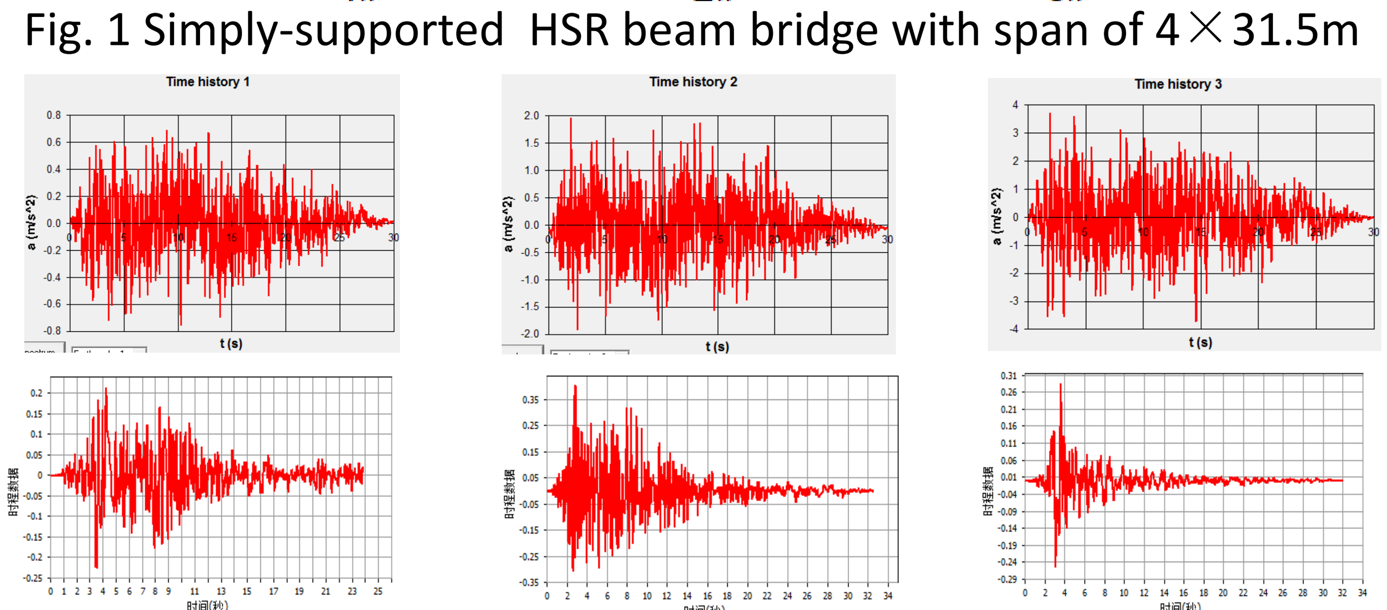

Fig. 2 Artificial fitted seismic waves(upper) and waves from PEER(lower)

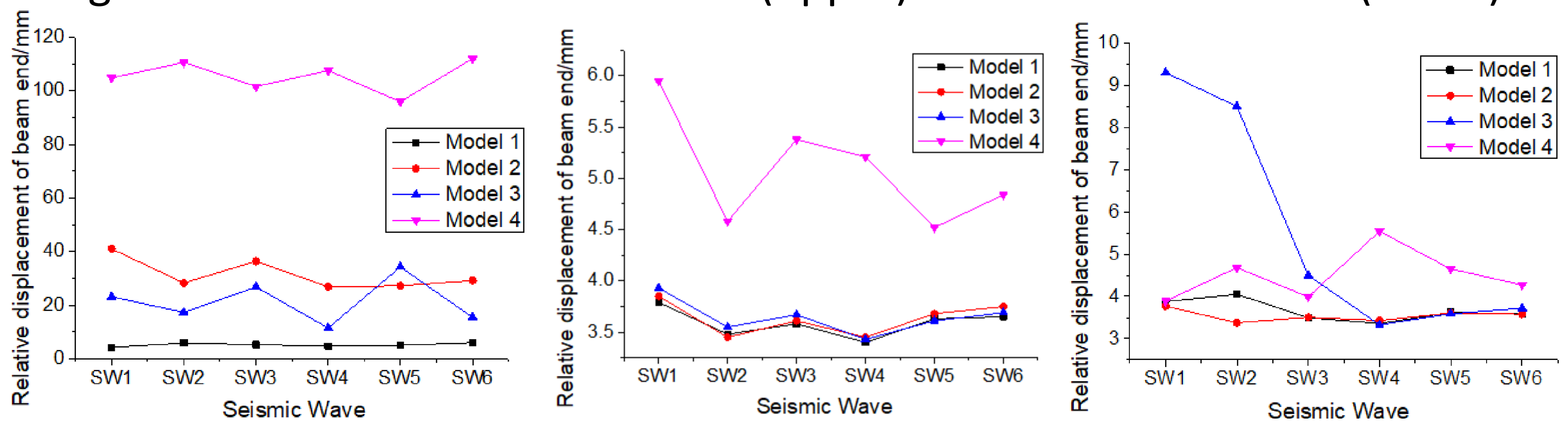

Fig. 3 Relative displacement at beam end under different cases (1#/2#/3#)

UNSEATING PREVENTION COUNTERMEASURES

Representative seismic damage of SSB bridge includes unseating, damage of pier and abutment, damage of bearings, etc. As an effective unseating prevention countermeasure, **seismic shear key(SSK)** is widely applied in HSR bridge design. Other measures include **viscous damper**, **steel damper unseating device** and **shock absorber**, etc. The performance of seismic shear key was carried out in this presentation. Hysteretic model of seismic shear key was shown in Fig. 4.

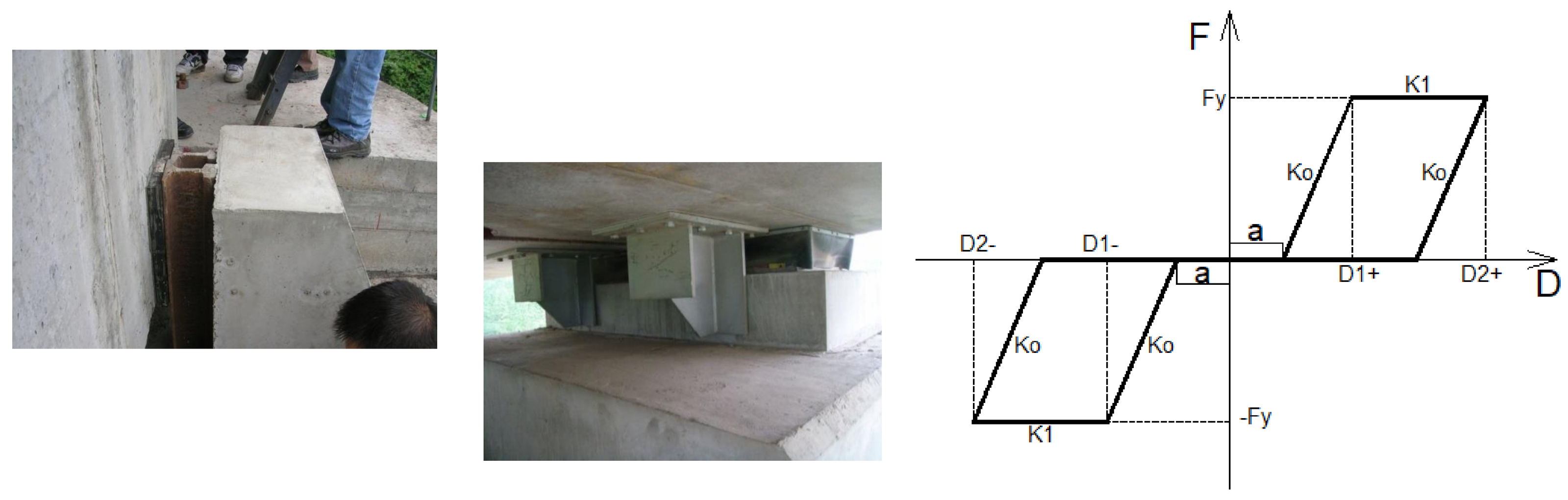

Fig. 4 Application of SSK and hysteretic model

PARAMETRIC STUDY OF TRANSVERSE SEISMIC SHEAR KEYS

Shear rigidity and initial gap were two major parameters for seismic shear keys. Considering different shear rigidity K0 as shown in table 1. In four cases, the value of initial yield deformation (D1-a) increased from o.5 to 4.0. And the initial gap was constant with the value of 7cm, the maximum force Fy was 3250kN. Influence of (D1-a) on bending moment of pier root was given in Fig.5. It showed that the bending moment had a tendency of decrease as value of (D1-a) increased, i.e. value of K0 decreased. Initial gap between SSK and beam varied from 3cm to 15cm as listed in table 2. Influence of initial gap on bending moment of pier root showed that the variation was not obvious for artificial fitted seismic wave. And decrease was obvious for PEER seismic waves.

Table 1 Shear rigidity of transverse SSK

No.	Initial gap (cm)	Initial yield deformation (D1-a) /cm	Final yield deformation (D2-a) /cm	Maximum force Fy (kN)	Equivalent stiffness K0
K1	7	0.5	1.5	3250	6.5e5
K2	7	1	3.0	3250	3.25e5
K3	7	2	6.0	3250	1.625e5
K4	7	4	12.0	3250	8.125e4

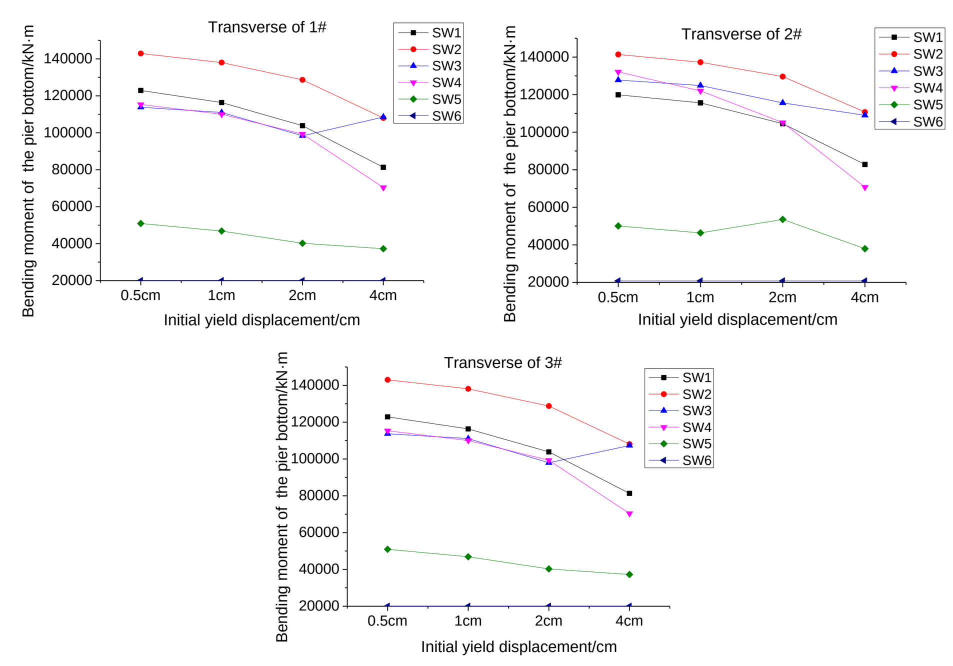

Fig. 5 Influence of (D1-a) on bending moment

Table 2 Initial gap between SSK and beam

No.	Initial gap (cm)	Initial yield deformation (D1-a) /cm	Final yield deformation (D2-a) /cm	Maximum force Fy (kN)	Equivalent stiffness K0
D1	3	1	3	3250	3.25e5
D2	7	1	3	3250	3.25e5
D3	11	1	3	3250	3.25e5
D4	15	1	3	3250	3.25e5

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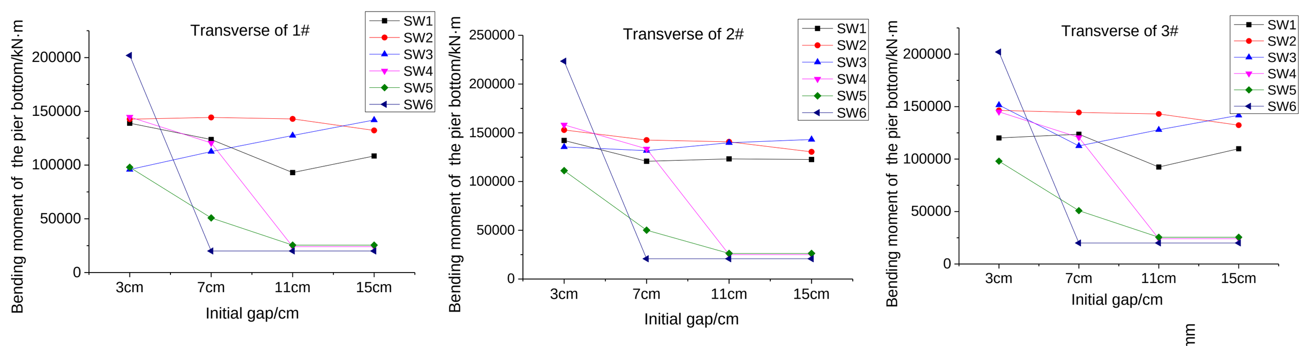
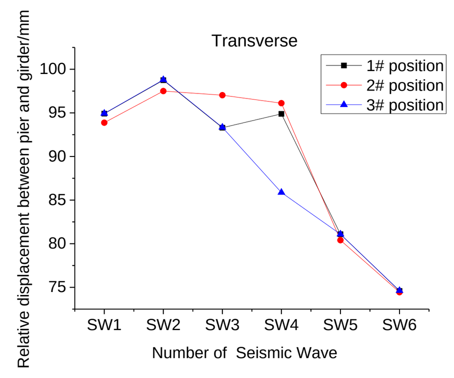


Fig. 6 Influence of initial gap on bending moment of pier root

Relative transverse displacement between pier and beam decreased obviously with maximum value from 472.3mm to 95.2mm (decrease rate 79.8%).



PARAMETRIC STUDY OF LONGITUDINAL SEISMIC SHEAR KEYS

Considering different shear rigidity K0 as shown in table 3. In four cases, the value of initial yield deformation (D1-a) increased from o.5 to 4.0. And the initial gap was constant with the value of 6cm, the maximum force Fy was 1000kN. Influence of (D1-a) on bending moment of pier root was given in Fig.7. It showed that the bending moment had a tendency of decrease as value of (D1-a) increased, i.e. value of K0 decreased. Initial gap between SSK and beam varied from 3cm to 9cm as listed in table 4. Influence of initial gap on bending moment of pier root showed that the variation was not obvious for artificial fitted seismic wave. And decrease was obvious for PEER seismic waves.

Table 3 Shear rigidity of longitudinal SSK

No.	Initial gap (cm)	Initial yield deformation (D1-a) /cm	Final yield deformation (D2-a) /cm	Maximum force Fy (kN)	Equivalent stiffness K0
Kz1	6	0.5	1.5	1000	2.0e5
Kz2	6	1	3	1000	1.0e5
Kz3	6	2	6	1000	5.0e4
Kz4	6	4	12	1000	2.5e4

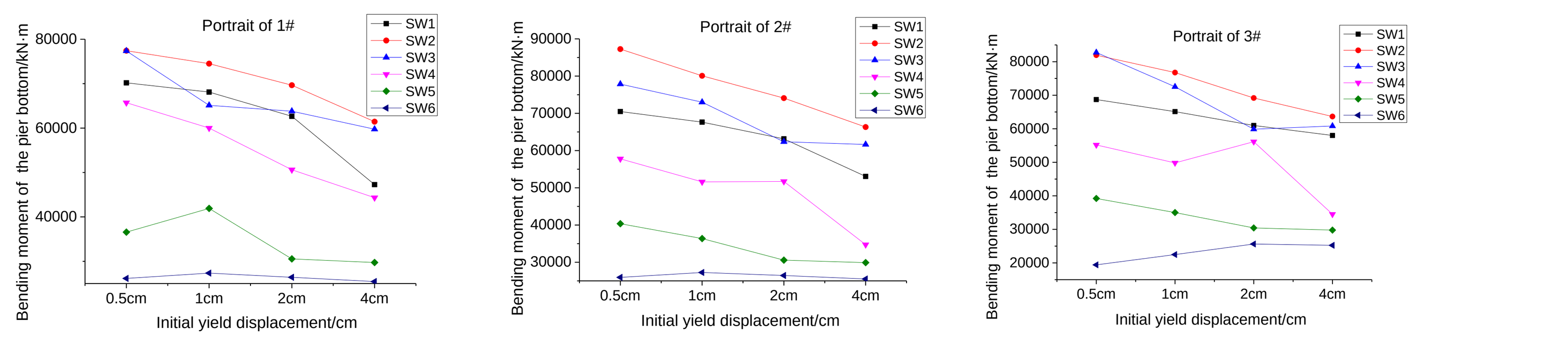


Fig. 7 Influence of (D1-a) on bending moment of pier root

Table 4 Initial gap between SSK and beam

No.	Initial gap (cm)	Initial yield deformation (D1-a) /cm	Final yield deformation (D2-a) /cm	Maximum force Fy (kN)	Equivalent stiffness K0
Dz1	3	1	3	1000	1e5
Dz2	6	1	3	1000	1e5
Dz3	9	1	3	1000	1e5

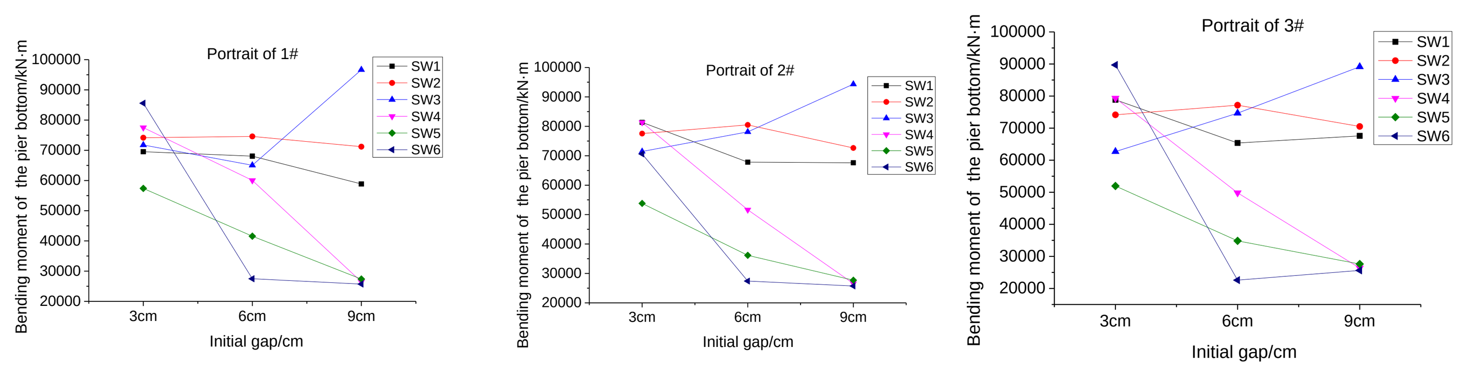
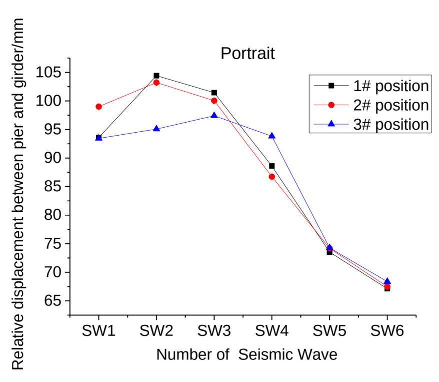


Fig. 8 Influence of initial gap on bending moment of pier root

Relative longitudinal displacement between pier and beam decreased obviously with maximum value from 667.5mm to 109.3mm (decrease rate 83.6%).



CONCLUSIONS

Characteristics of pounding at beam end under strong earthquake was studied, dealing with a typical HSR PC simply-supported beam bridge with span of 4×31.5m. Performance of seismic shear keys as a widely used unseating prevention device were also analyzed. Several conclusions were as follows:

(1) Pounding at beam end was caused by obvious relative displacement. It was influenced by bearing arrangement, performance of bearing and pier height. Compared to relative displacement between pier and beam, the relative displacement between adjacent beams was much smaller.

(2) For models without seismic shear keys, the maximum relative displacement in the longitudinal and transverse direction was 472.3mm and 667.5mm respectively considering the bearing damage, which resulted in unseating risk.

(3) Design of seismic shear keys was easy and its unseating effect was obvious. After considering the effect of SSK, the relative displacement between pier and beam decreased to 109.2mm and 95.2mm in longitudinal and transverse direction, respectively. The decrease rate was more than 75%. And the response was less at the pier root.

(4) SSK shall have the function of fuse to make the pier safe. According to the parametric study, rigidity of SSK in the transverse direction shall be less than 1e6 kN/m, and 1e5 kN/m for longitudinal shear. The proper initial gap shall be varied from 7cm to 11 cm for the transverse shear keys. And the value for longitudinal shear keys shall be from 4cm to 7cm.

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