Seismic behaviour of an earthquake-resilient prefabricated beam-column cross joint

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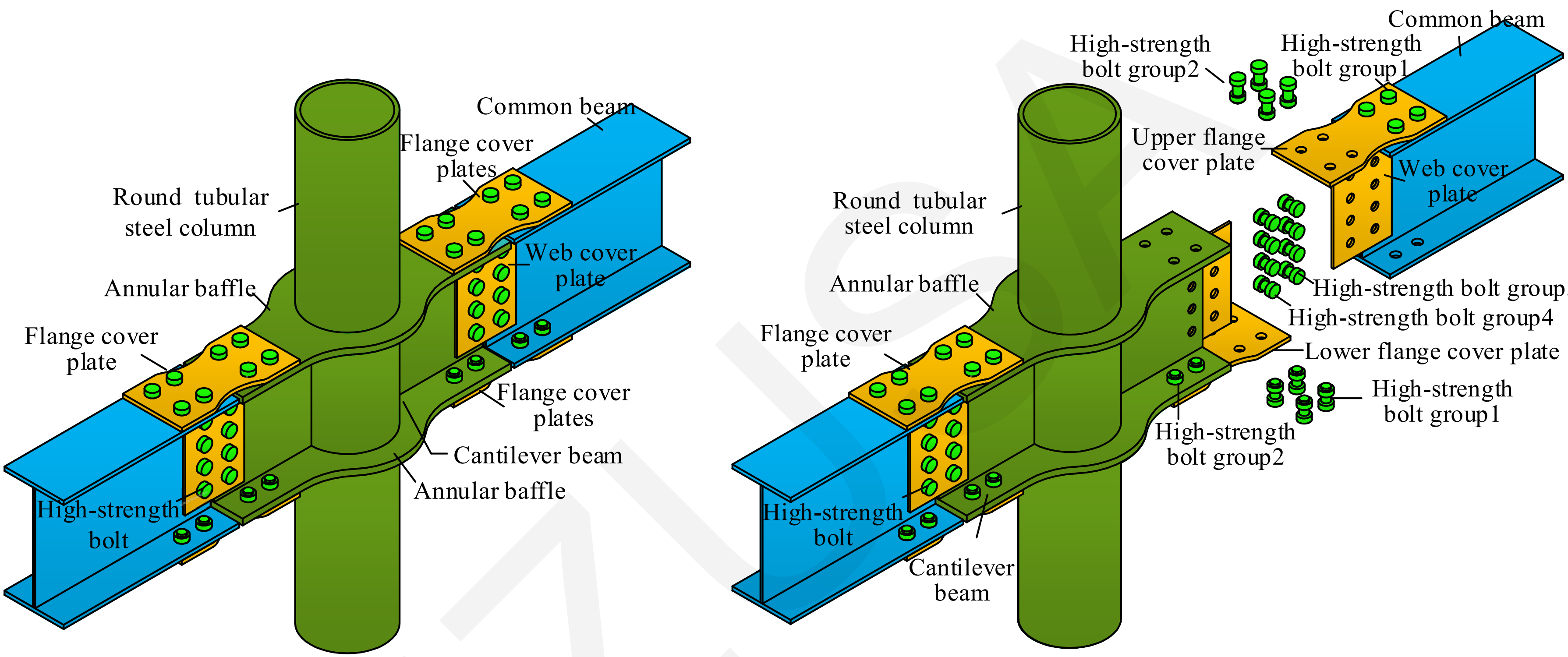
Highlights

- A new type earthquake-resilient prefabricated beam-column cross joint (ERPCJ) is put forward.
- The theory behind the design of the ERPCJ is proposed and verified by numerical simulation using eight ERPCJ models.
- The hysteretic behaviour of the ERPCJ was investigated using the finite element (FE) method.
- Cyclic loading and repairing tests were conducted on a basic specimen, and the rationality of the design theory was verified.
- Seismic performance and post-earthquake resilience performance of the joint were investigated.

Constitution of ERPCJ



The ERPCJ consists of a round tubular steel column with cantilever beams, common beams, and replaceable connecting parts. Round tubular steel columns with cantilever beams and common beams can be manufactured in factories and quickly installed at the construction site by connecting the flanges and webs with cover plates and high-strength bolts

Design theory of ERPCJ

The design of the flange cover plate directly influences whether the ERPCJ can be meet the seismic design requirements.

As the flange cover plate works for the overall bending of the combined section, its stress should satisfy the requirement of Eq. (1).

$$\sigma_{zt} = \frac{P_{sby} L_{sb}}{\chi_1 I_{cov}} \left(h_b / 2 + t_{cov,f} \right) \leq f_{cov,y},$$

Besides, compression flange cover plates should meet the stability bearing requirement as given in Eq. (2).

$$\sigma_{jb} = \frac{N_{cov,y}}{\varphi_{cov} A_{cov}} \leq f_{cov,y},$$

Once $t_{cov,f}$ is determined, the yield load P_y can be obtained in the same way, as given in Eq. (5).

$$P_y = \min \left(\frac{\varphi_{cov} A_{cov} h_{cov,0}}{\eta_1 L_{sb}} f_{cov,y}, \frac{\chi_1 I_{cov}}{\left(h_b / 2 + t_{cov,f} \right) L_{sb}} f_{cov,y} \right).$$

Finite element model

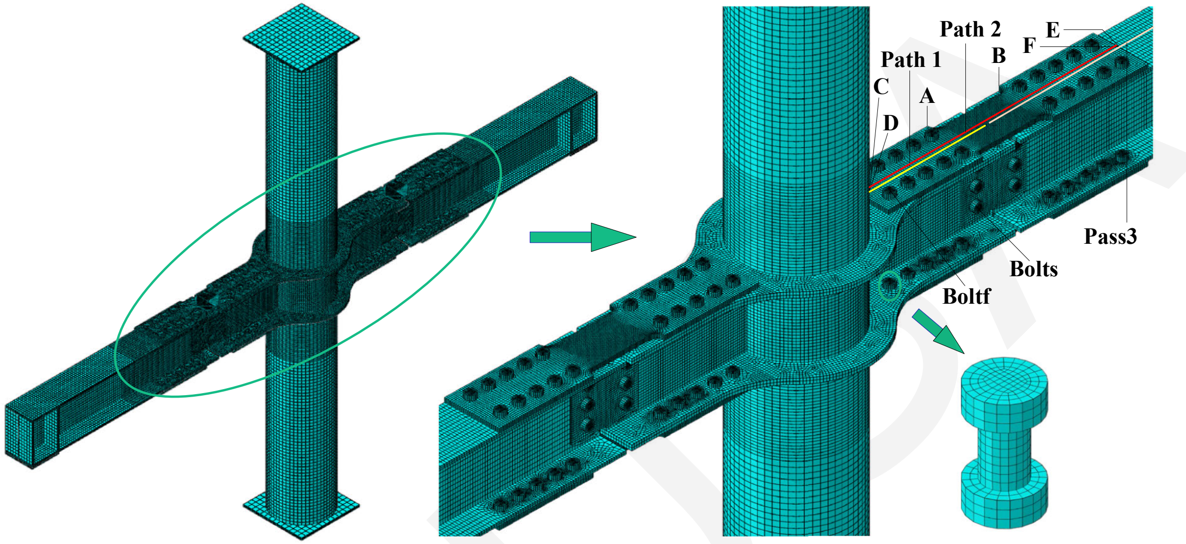


Table 1 Parameters of specimens

Model	$t_{cov,f}$ (mm)	L_g (mm)	$l_{bo,m}$(mm)	Material of flange cover plate
X1-K1-SJ1	16	20	320	Q235B
X2-K1-SJ2	16	20	320	Q235B
X3-K1-SJ3	16	20	320	Q235B
X3-K1-SJ4	12	20	320	Q235B
X3-K1-SJ5	16	20	320	Q345B
X3-K1-SJ6	16	20	160	Q235B
X3-K1-SJ7	16	6	320	Q235B
X3-K2-SJ8	16	20	320	Q235B

Verification of the design theory

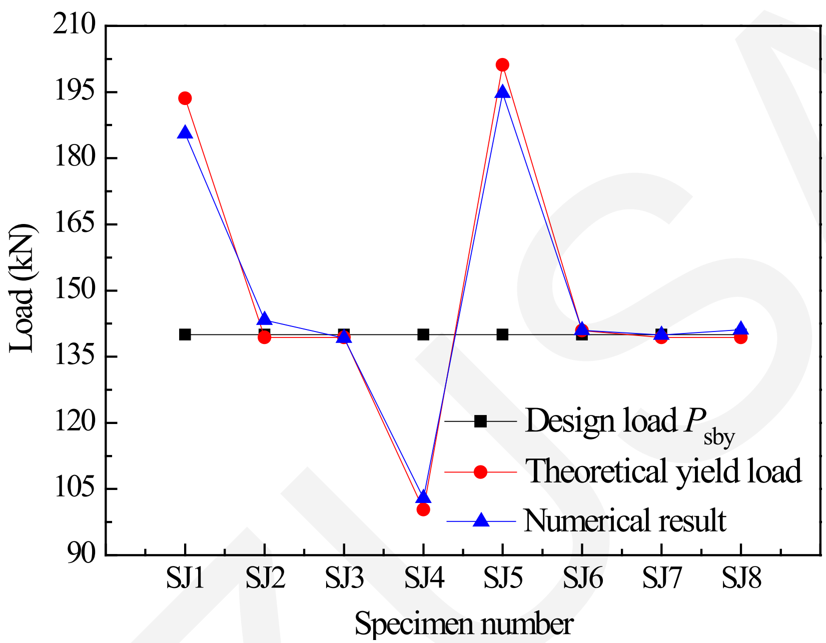


Fig. 8 shows the design load, theoretical yield load and numerical results of the yield load for all ERPCJ models. The theoretical yield load was calculated using Eq.(5). The design load is the yield load of the common beam over the whole span, P_{sby}. The figure shows that the yield load of the ERPCJ obtained by FE analysis of each specimen is in good agreement with the theoretical value: the deviation is within 5%, which proves the accuracy of the design theory.

Hysteretic loop of each ERPCJ

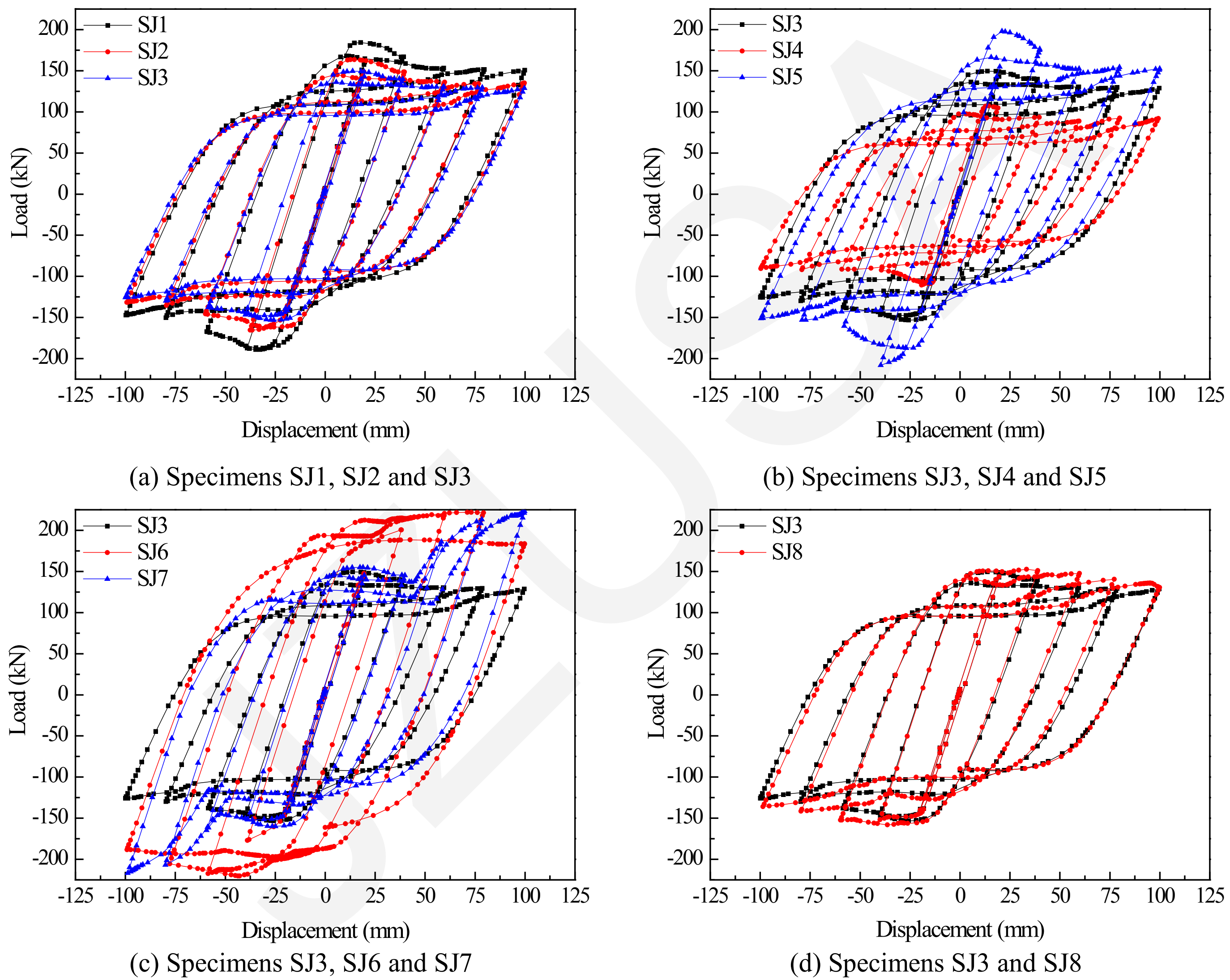
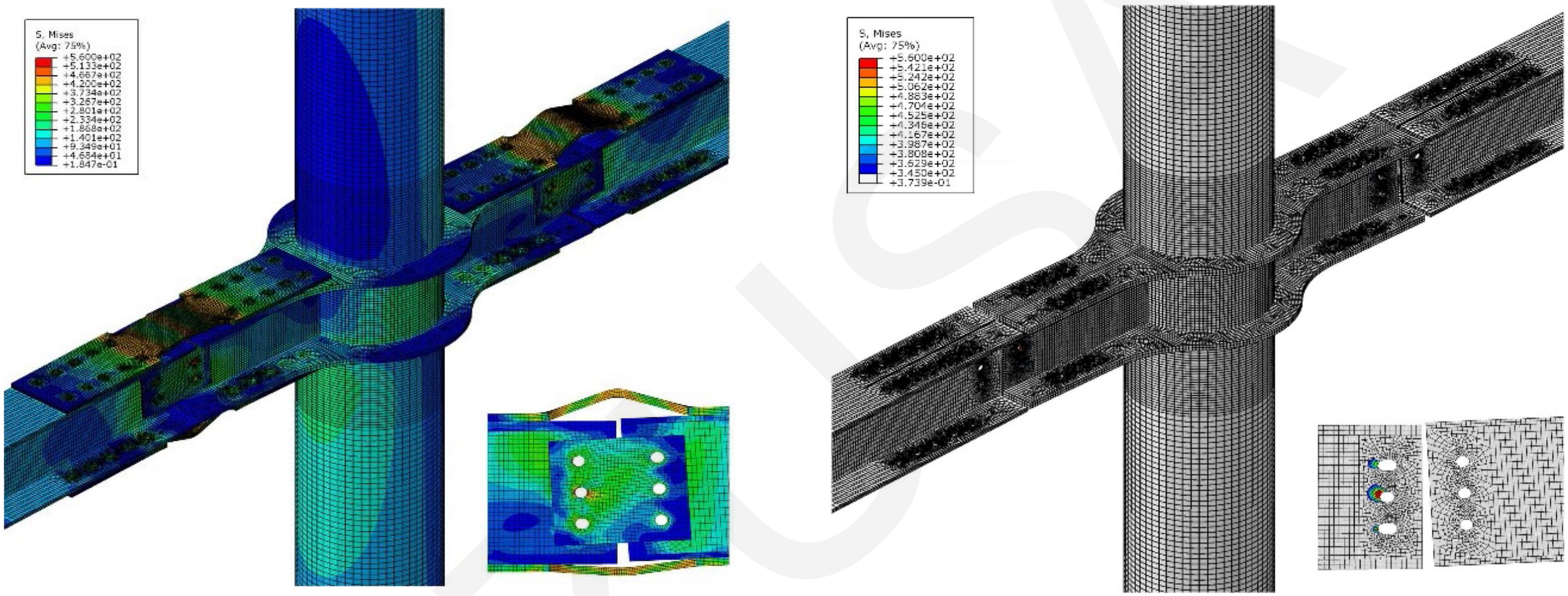


Fig. 9 Hysteretic loops

Failure modes of ERPCJ



(b) Failure mode and von Mises stress on specimen SJ3

On the whole, SJ3 shows good earthquake-resilient behaviour. Its beam and column are in the elastic stage when the rotation of ERPCJ is 0.05 rad. It is necessary to replace only the connection members and high strength bolts; thus, it meets the requirements of earthquake resilience.

Cyclic loading test

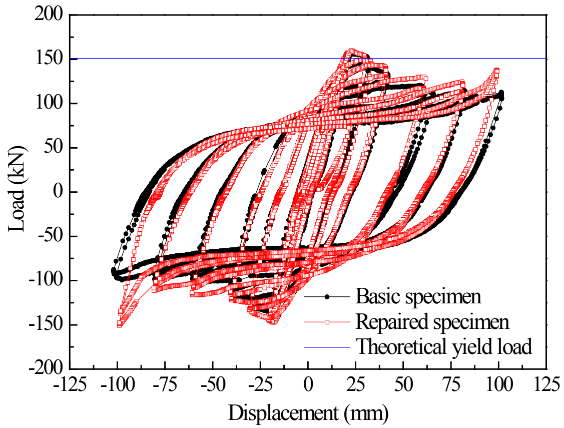


Fig. 16 Hysteretic curves

Fig. 17 Flange cover plate deformation of the basic specimen

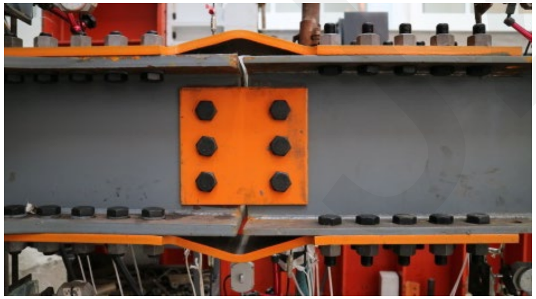


Fig. 19 Flange cover plate deformation of the repaired specimen

Fig. 18 Deformation of the basic specimen

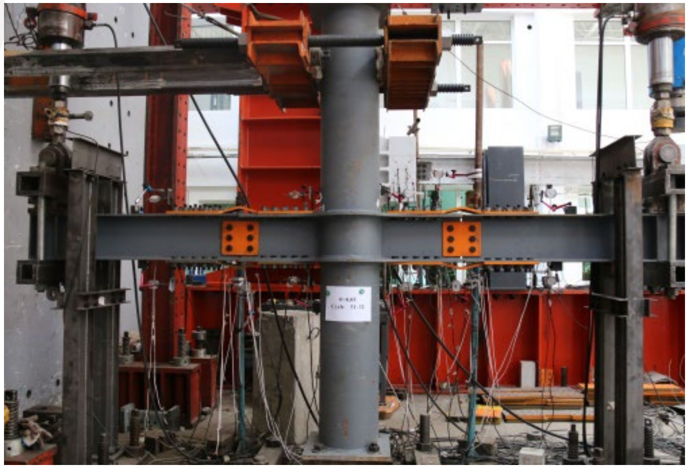


Fig. 20 Deformation of the repaired specimen

Conclusions

- 1. Numerical analyses showed that the proposed design theory could accurately predict the yield load of the ERPCJ. A well-designed ERPCJ can have a good bearing capacity and hysteretic behaviour. Only the replaceable connecting parts need to be replaced after an earthquake to recover the structure.
- 2. If a straight dog-bone profile is used for weakening in the flange cover plate, the ductility of the joint would be improved and the bearing capacity could be ensured. The thickness and material properties of the flange cover plate directly influence the yield load of the ERPCJ. Therefore, the main parameter values should be selected strictly according to the design theory.
- 3. The short distance between the middle bolts had little influence on the yield load of the joint, but it made the flange cover plate difficult to buckle. This made the joint too strong to protect beams, and columns remained in the elastic state. If the gap between the beams is small, collision would occur between the cantilever beam and the common beam, which is against the requirements of earthquake resilience.
- 4. Experiments showed that the design theory could approximately predict the yield load of the specimen. Furthermore, the test results showed that the ERPCJ designed by the proposed theory had a good bearing capacity, collapse resistance capacity, seismic performance, and post-earthquake resilience performance, and could meet the requirements of earthquake resilience.