



同濟大學

TONGJI UNIVERSITY



# Experimental Study on Lateral Resistance of Timber Post and Beam Structures

**Reporter :**

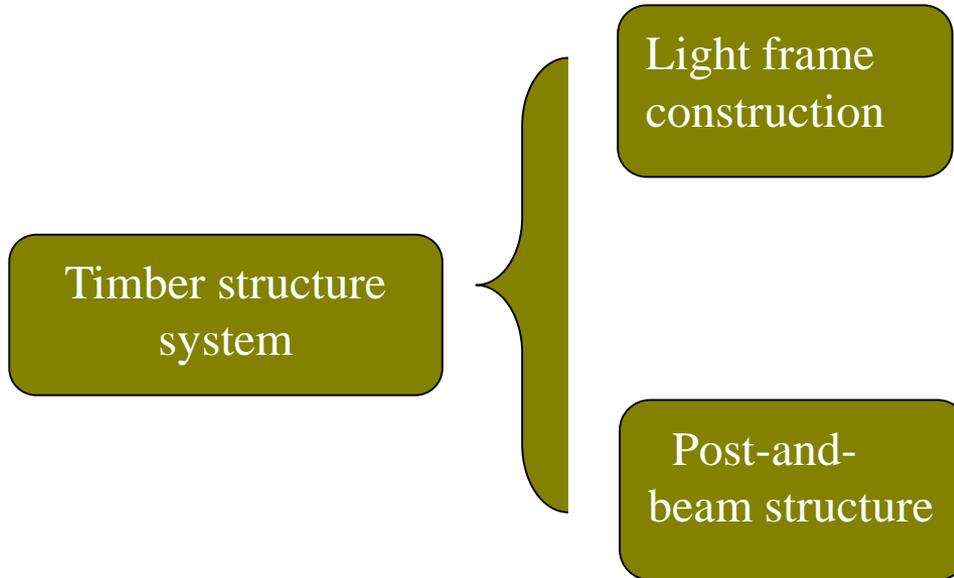
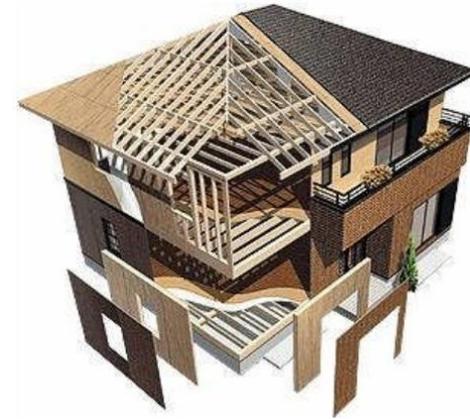
**LIU Yingyang**

**2013.08.20**

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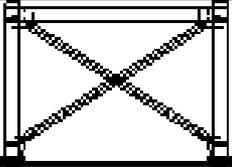
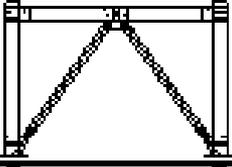
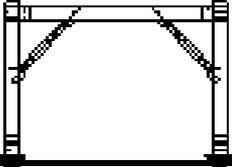
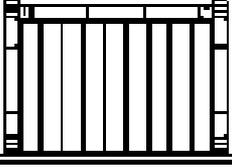


# 1. Structural system



- Light frame construction is composed of wood-framed shear walls, timber floors and timber roof.
- Post-and-beam structure generally has two types of members: columns and beams.

## 2. General situation of the test

Specimen names	Lateral resisting systems	Sketch of the specimens
MF1 CF1 CF2	Pure post and beam frame	
MXB1 CXB1 CXB2	X-brace	
CKB1 CKB2	K-brace	
CHB1	Knee-brace	
CFW1	Light frame wood shear walls	

**F**—Post and beam structure

**XB**—X-brace

**KB**—K-brace

**HB**—Knee-brace

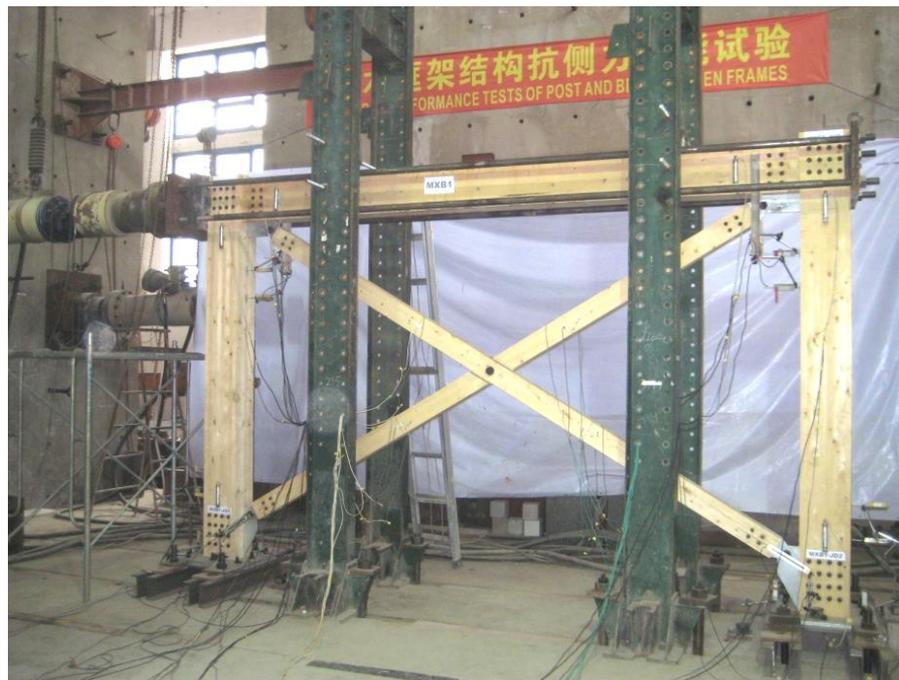
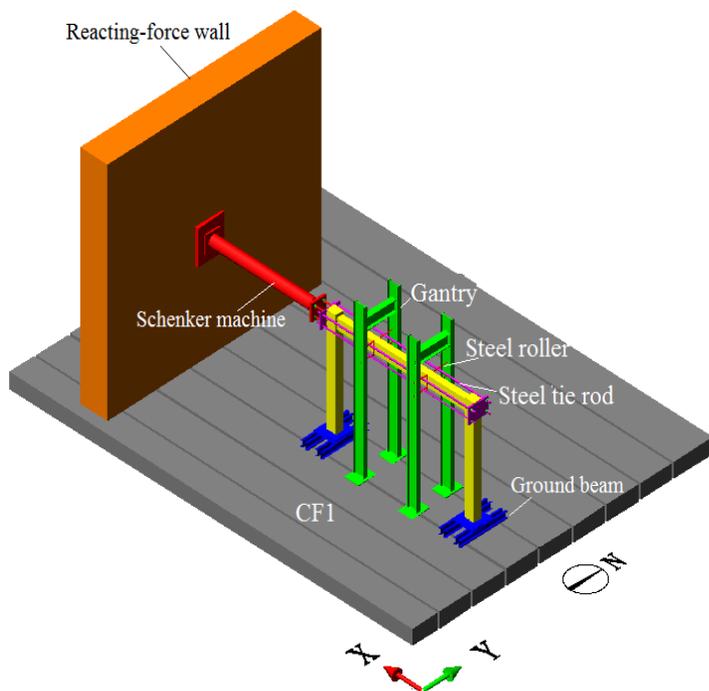
**W**—Light frame wood  
shear walls

**M**—Monotonic test

**C**—Cyclic test

## 2. General situation of the test

### (1) Test setup

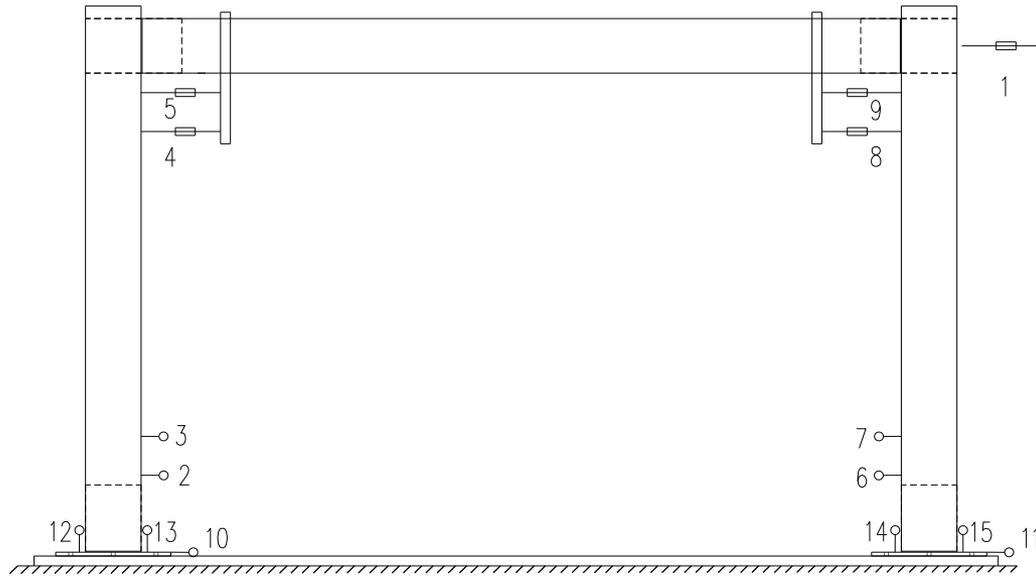


Tests were carried out by the static test system of the state key laboratory of tongji university



## 2. General situation of the test

### (2) Test instrumentation

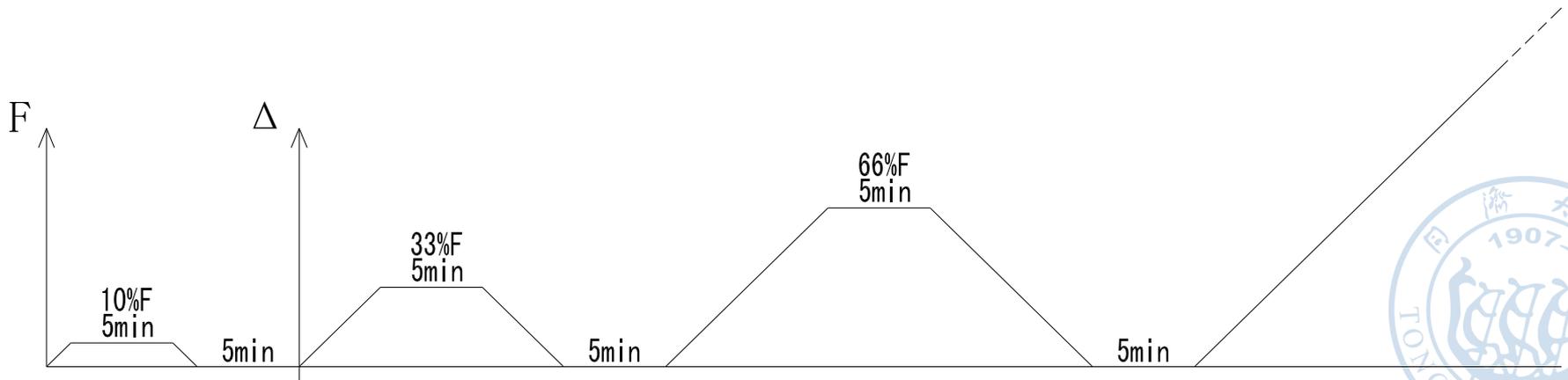


- ① Loading force, exported directly by the Schenker machine.
- ② Horizontal displacement of the top of the frame column.
- ③ Relative rotation of the joint, measured by the couple of the displacement sensors.
- ④ Horizontal slip and pulling up of the frame column.

### (3) Test procedure

#### ① Monotonic test

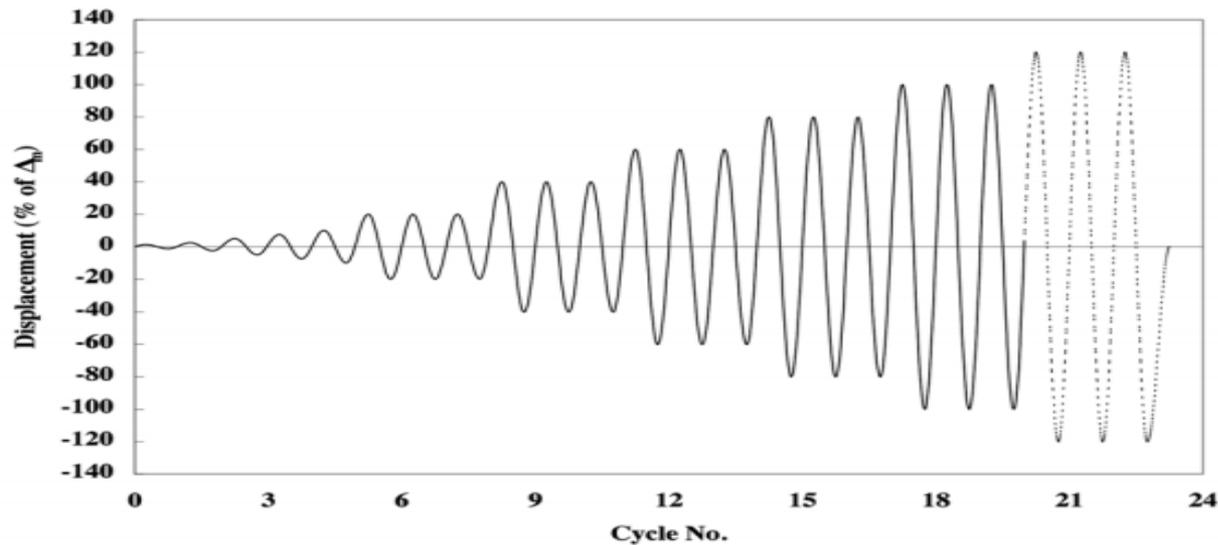
- 1) Apply preload of approximately 10% of estimated ultimate load and hold for 5 min to seat all connections. Remove the load, wait 5 min, and read all gages as the initial readings.
- 2) At load levels approximately one third and two thirds of the estimated ultimate load, remove the load and record the recovery of the structure after 5 min. Reload to the next higher load level above the back off load.
- 3) Continue loading until ultimate load is reached.



### (3) Test procedure

#### ① Cyclic test

- 1) The first displacement pattern consists of five single fully reversed cycles at displacements of 1.25 %, 2.5 %, 5 %, 7.5 %, and 10 % of the ultimate displacement.
- 2) The second displacement pattern consists of phases, each containing three fully reversed cycles of equal amplitude, at displacements of 20 %, 40 %, 60 %, 80 %, 100 %, and 120 % of the ultimate displacement.



## 2. General situation of the test

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### (4) Test failure criterion

- 1) Load decreased to the 80% of the ultimate load.
- 2) The lateral displacement turned to 250mm.



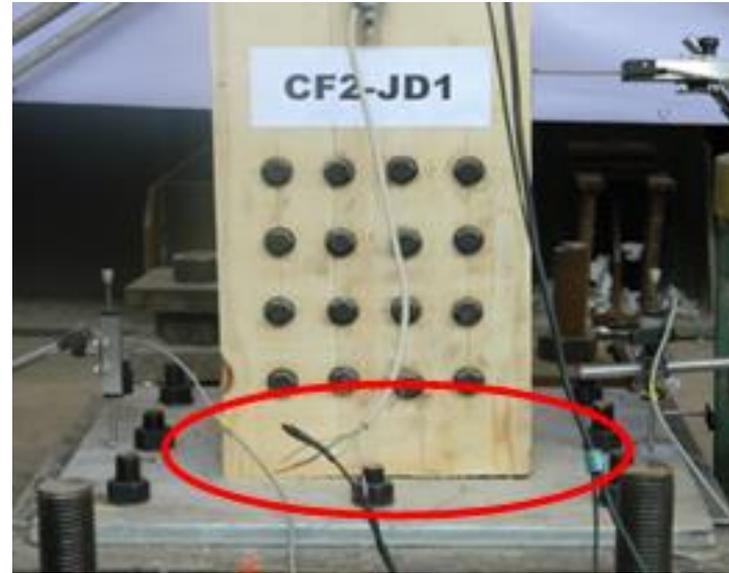
## 3. Experimental phenomenon and failure mode

### 3.1 Unbraced structure system (CF1、CF2)

When lateral displacement turned to 10 % of the ultimate displacement (26mm), the joints showed up local pressing close.

The force transmitting of the beam-column joints: ①Indirect force transmitting: column→bolts→steel plate→bolts→beam; ②Direct force transmitting by the local pressing close.

The force transmitting of the column-bottom joints: ①Indirect force transmitting: column→bolts→steel plate→foundation; ②Direct force transmitting by the local pressing close.



## 3. Experimental phenomenon and failure mode

### 3.1 Unbraced structure system (CF1、CF2)

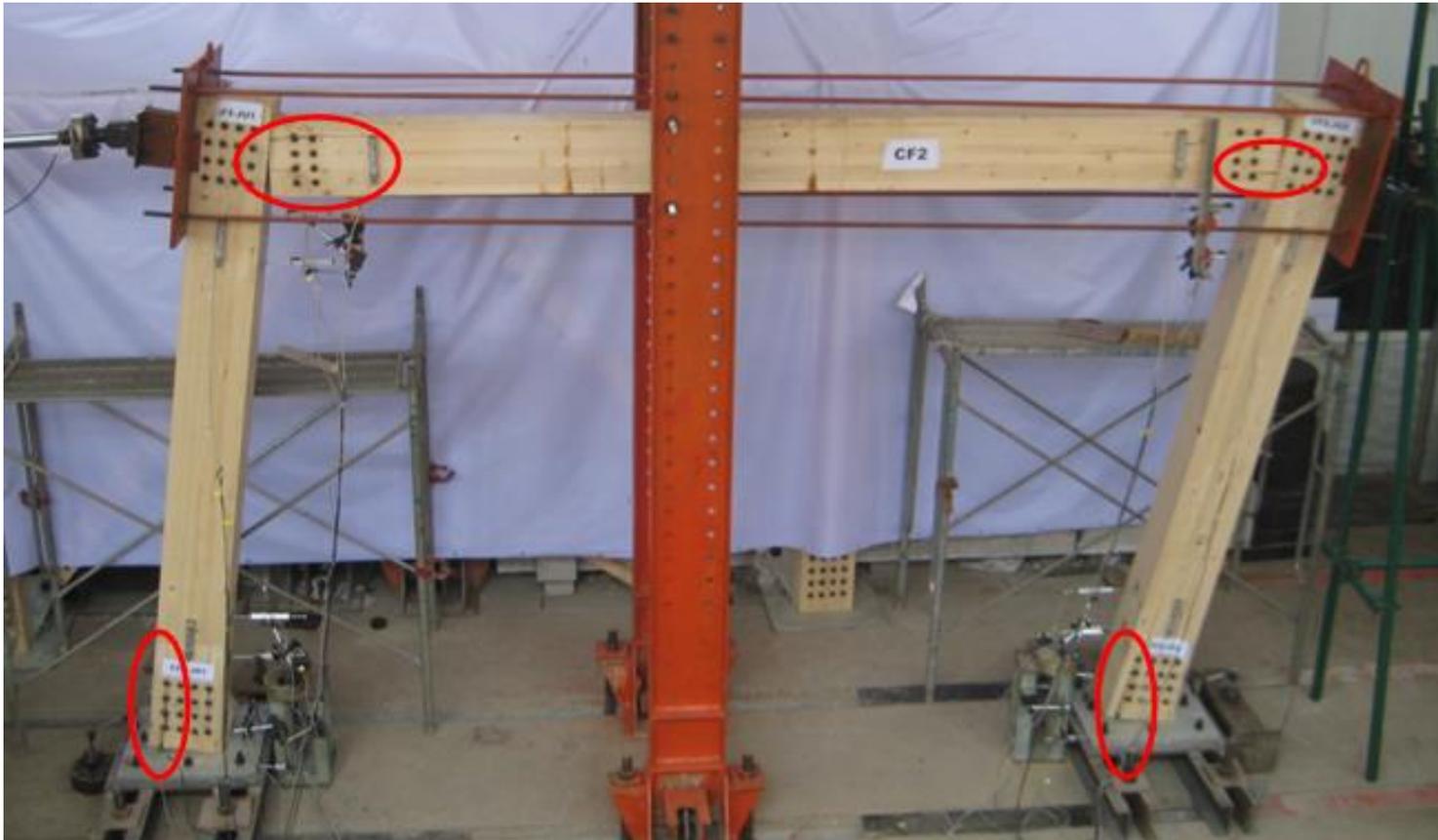
When lateral displacement turned to 10%~20% of the ultimate displacement (26mm~52mm), the column-bottom joints splitted because of the local pressing close. The cleavage cracks of the ends of the beam happened when the lateral displacement turn to 40%~60% of the ultimate displacement (104mm~156mm). The cleavage cracks of both the column-bottom joints and the ends of the beam continued to develop in the subsequent loading process.



## 3. Experimental phenomenon and failure mode

### 3.1 Unbraced structure system (CF1、CF2)

The destruction was only found in the joints, while the mid-span section of both the beam and column was intact, showing up the “weak-joint and strong-member”.



## 3. Experimental phenomenon and failure mode

### 3.2 X-brace structure system (CXB1、CXB2)

When lateral displacement were in 0~40% of the ultimate displacement (0~16mm), there was not any significant phenomenon of destruction. The wood and the bolts contacted, making some sound.

When the lateral displacement turned to 40%~60% of the ultimate displacement (16mm~24mm), the out-of-plane deformation of the brace appeared.



out-of-plane deformation (thrust)

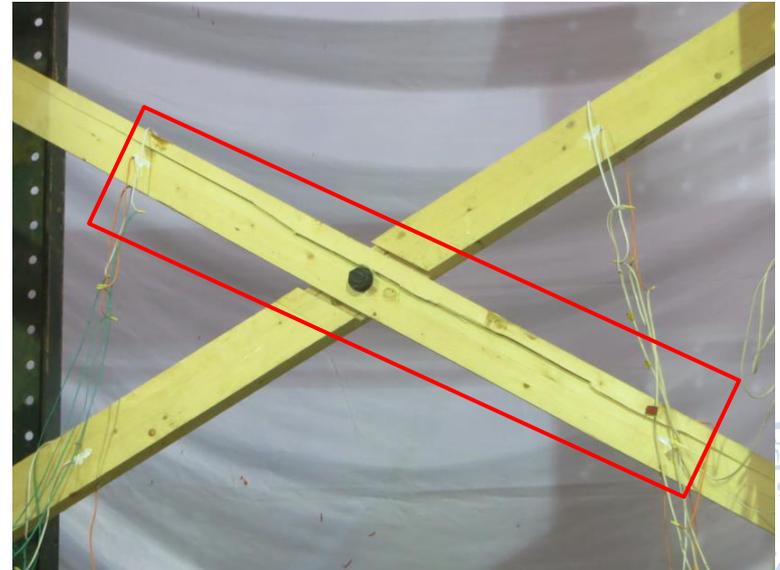
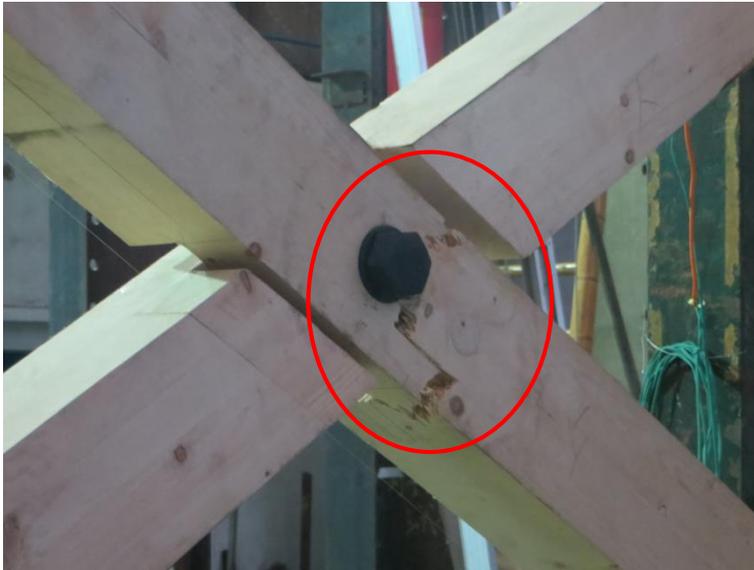


out-of-plane deformation (pulling)

## 3. Experimental phenomenon and failure mode

### 3.2 X-brace structure system (CXB1、CXB2)

When applying thrust load on the specimen of CXB1 at 31.6mm, in the second reversed cycles of the amplitude of the 80% of the ultimate displacement (32mm), the tensile element of brace splitted significantly but the compressive element of brace was intact. When applying pulling load at -31.1mm in the same cycle, the previous compressive one splitted under the tensile stress. The significant load drop in the third cycle meant the destruction of the structure.



Cleavage of the tensile element of brace

### 3. Experimental phenomenon and failure mode

#### 3.2 X-brace structure system (CXB1、CXB2)

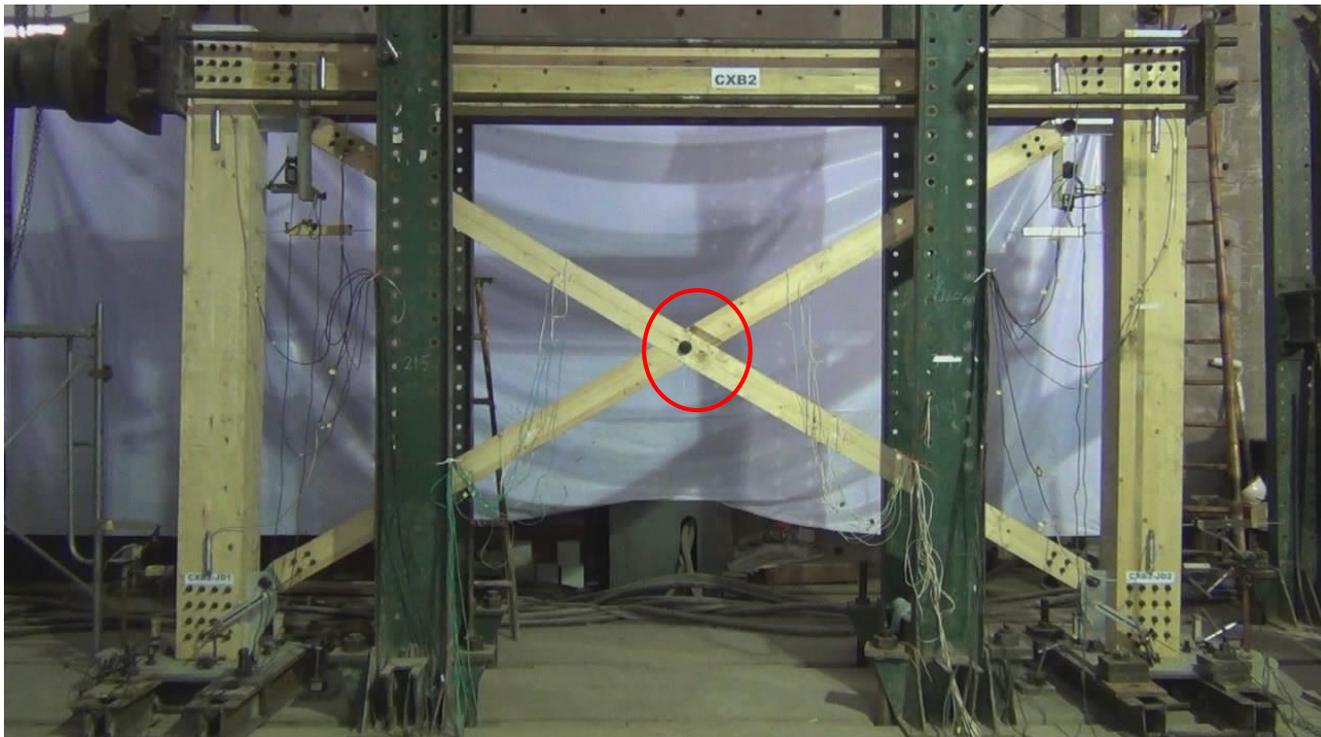


General failure mode of CXB1

### 3. Experimental phenomenon and failure mode

#### 3.2 X-brace structure system (CXB1、CXB2)

The failure mode of the specimen of CXB2 was similar to CXB1.

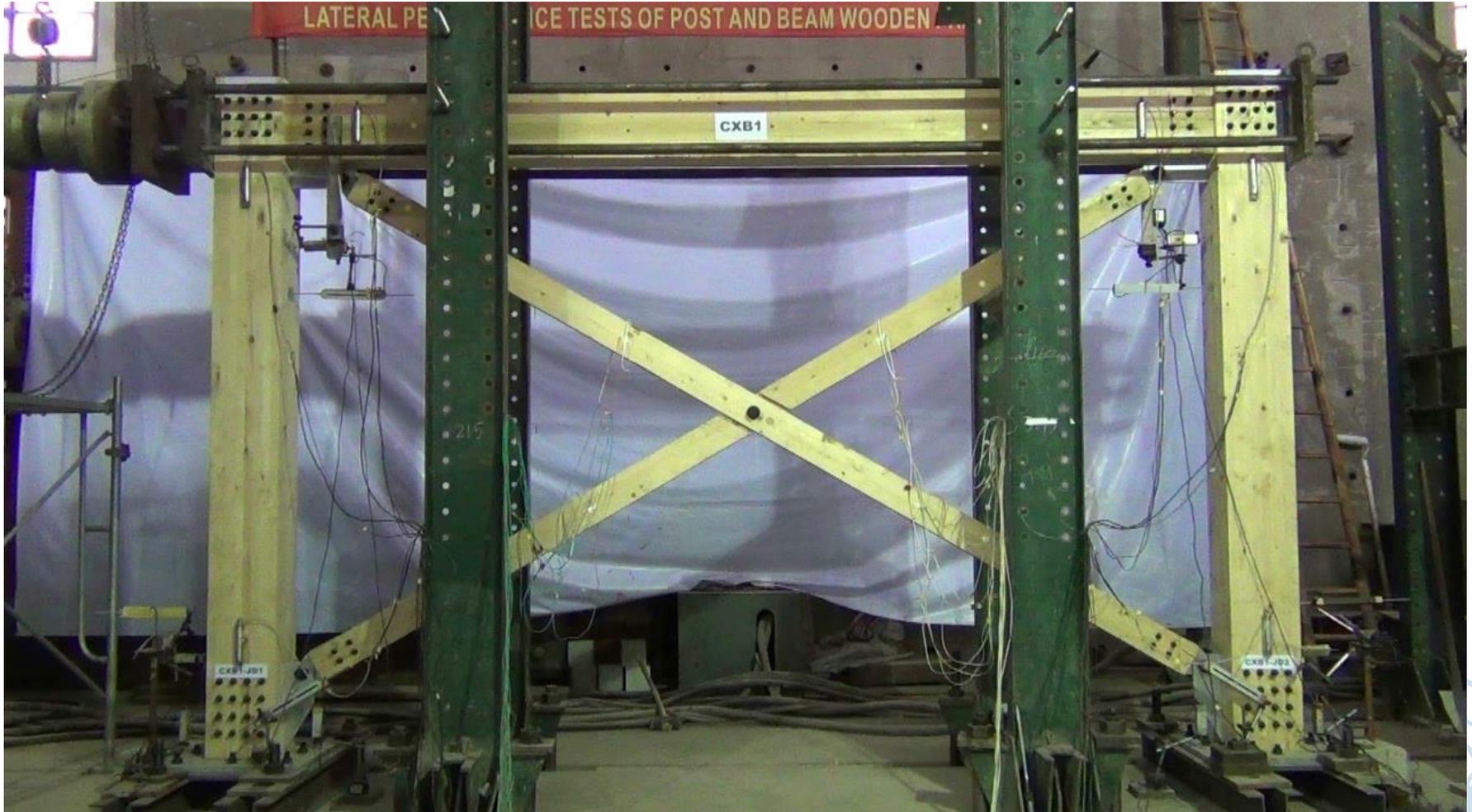


General failure mode of CXB2

### 3. Experimental phenomenon and failure mode

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#### 3.2 X-brace structure system (CXB1、CXB2)



## 3. Experimental phenomenon and failure mode

### 3.3 K-brace structure system (CKB1、CKB2)

When lateral displacement were in 0~40% of the ultimate displacement (0~16mm), there was not any significant phenomenon of destruction. The wood and the bolts contacted, making some sound.

The steel plate of the brace joints rotated slightly when the lateral displacement turned to 16mm~24mm. The column-bottom joints splitted, When lateral displacement turned to 24mm~32mm. The cleavage cracks of the ends of the beam happened when the lateral displacement turn to 32mm~40mm.



## 3. Experimental phenomenon and failure mode

### 3.3 K-brace structure system (CKB1、CKB2)

When lateral displacement of the specimen of CKB1 turned to 140%~160% of the ultimate displacement (56mm~64mm), the bolts of the brace joints were cut, meaning the destruction of the structure.

The failure mode of the specimen of CKB2 was similar to CKB1.



## 3. Experimental phenomenon and failure mode

### 3.4 Knee-brace structure system (CHB1)

When lateral displacement were in 0~40% of the ultimate displacement(0~16mm), there was not any significant phenomenon of destruction. The wood and the bolts contacted, making some sound.

When lateral displacement turned to 24mm~32mm, the column-bottom joints splitted. When lateral displacement turned to 64mm~80mm, the steel plate of the brace joints rotated slightly.

When lateral displacement turned to 80mm~152mm, the bolts of the brace joints were cut. In this loading process, the bearing load reached the peak.



## 3. Experimental phenomenon and failure mode

### 3.4 Knee-brace structure system (CHB1)

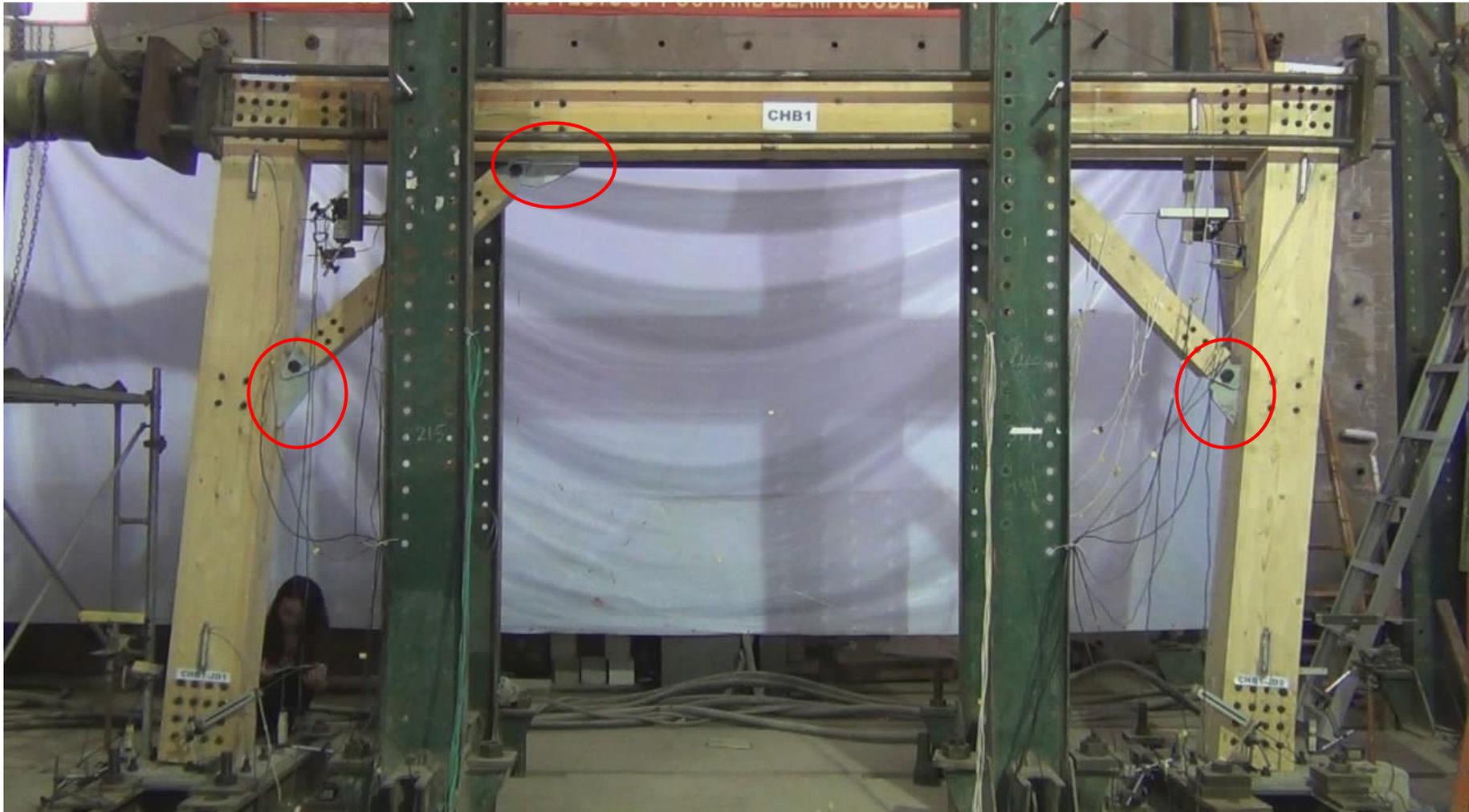
In the subsequent loading process, although the bolts were cut, the braces stuck in the wooden frame continued to transmit the compressive force, resulting the slowly decline of the bearing load.



### 3. Experimental phenomenon and failure mode

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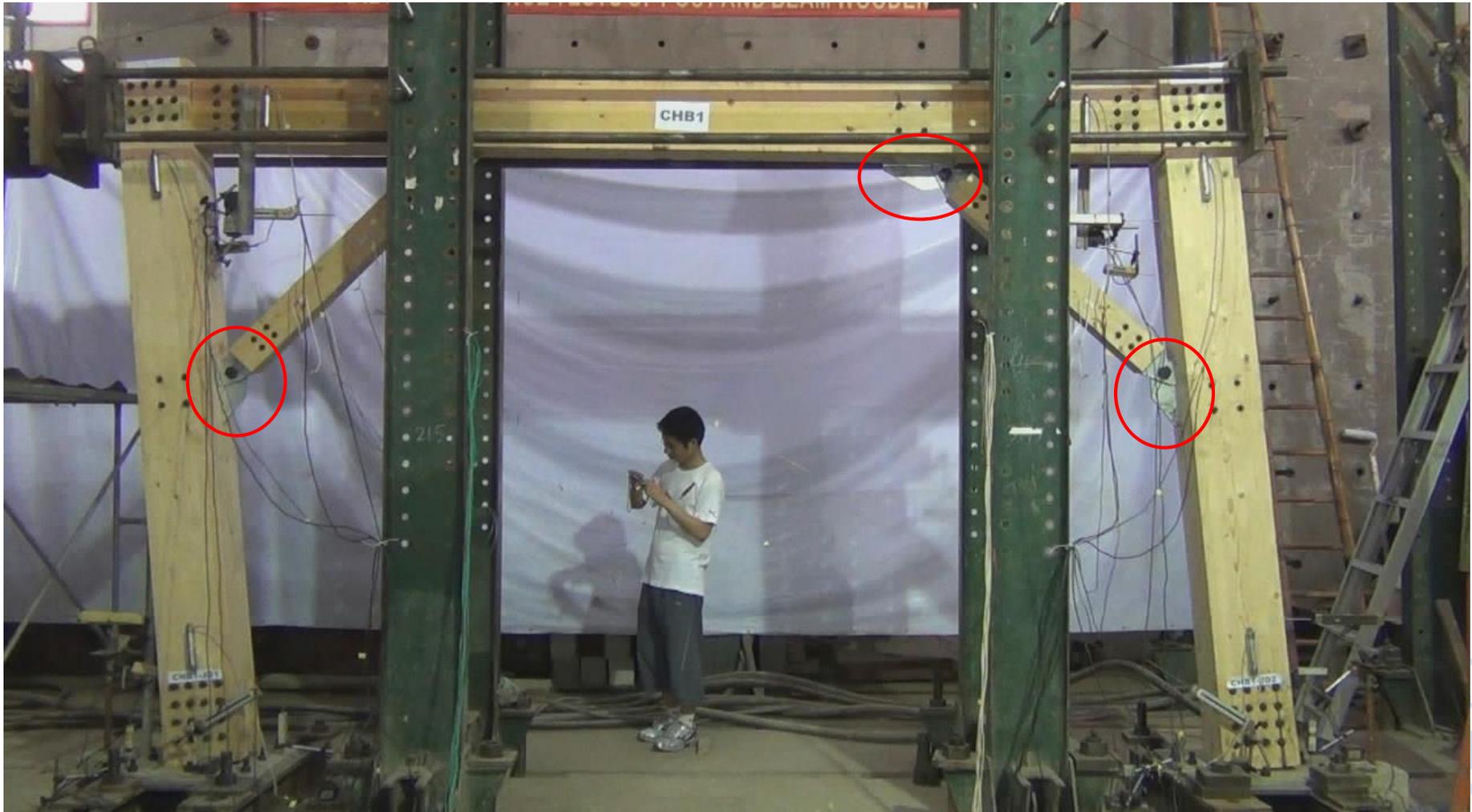
#### 3.4 Knee-brace structure system (CHB1)



### 3. Experimental phenomenon and failure mode

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#### 3.4 Knee-brace structure system (CHB1)



## 3. Experimental phenomenon and failure mode

### 3.5 Filling-in light-frame wood shear walls structure system (CFW1)

When lateral displacement were in 0~80% of the ultimate displacement(0~32mm), there was not any significant phenomenon of destruction. The wood, the bolts and the nails contacted, making some sound.

When lateral displacement turned to 40mm~56mm, the nail were striped gradually form the panels and the column-bottom joints splitted. When lateral displacement turned to 64mm~80mm, the striping of the nails from the panels and the cleavage cracks of the column-bottom joints continued to develop. When the lateral displacement turned to 80~232mm, the panels striped from the studs, leading to the stagger displacement between the panels.



### 3. Experimental phenomenon and failure mode

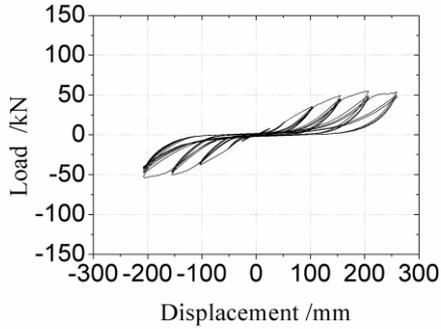
#### 3.5 Filling-in light-frame wood shear walls structure system (CFW1)

Although the nails became invalid gradually, but the hooping effort of the wooden frame maintained the load bearing capacity, showing up a good ductility.

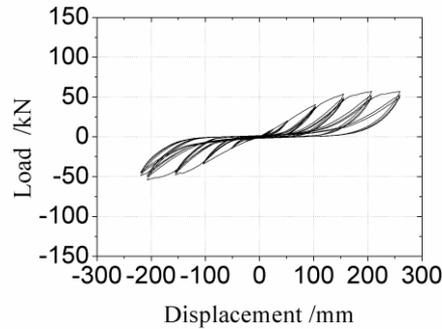


# 4. Experimental results and analysis

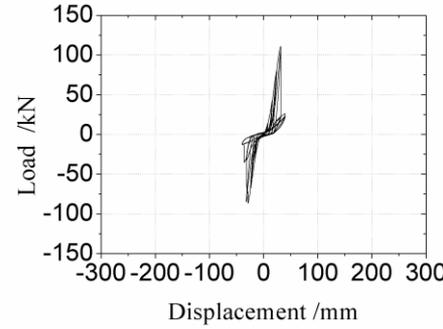
## 4.1 Hysteresis curves



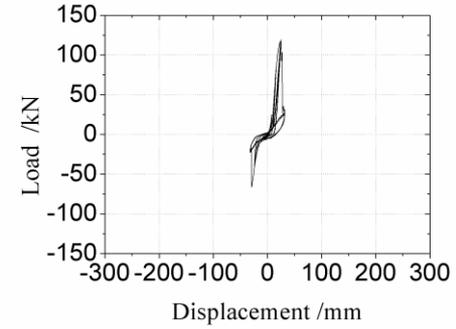
**CF1**



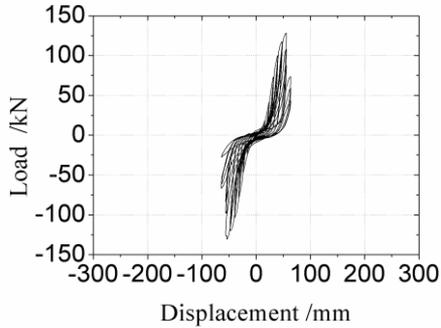
**CF2**



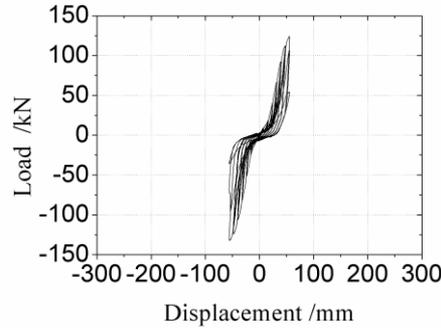
**CXB1**



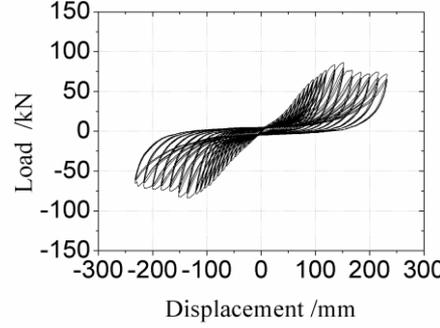
**CXB2**



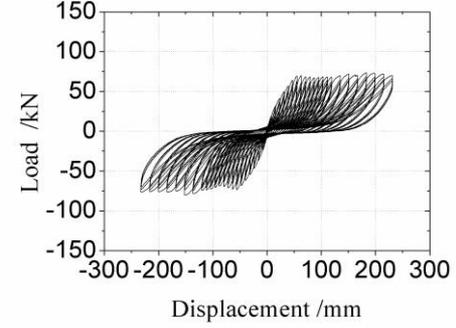
**CKB1**



**CKB2**



**CHB1**



**CFW1**

# 4. Experimental results and analysis

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## 4.1 Hysteresis curves

Conclusion can be drawn from the hysteresis curves:

- 1) All the hysteresis curves appear pinching, resulting from the slip of the joints. It is the primary clearance and the the deformation of wood perpendicular to the grain, that lead to the slip.
- 2) Unbraced structure system shows low lateral stiffness, and does not performan well in energy dissipation.
- 3) X-brace structures and K-brace structures provide high elastic stiffness, but low ductility. The failure mode belongs to brittle failure.
- 4) Knee-brace structures have better elastic stiffness than unbraced structures. Knee-brace structures also show a good ductility. It is because, the braces, stuck in the wooden frame, continue to transmit the compressive force.



# 4. Experimental results and analysis

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## 4.1 Hysteresis curves

Conclusion can be drawn from the hysteresis curves:

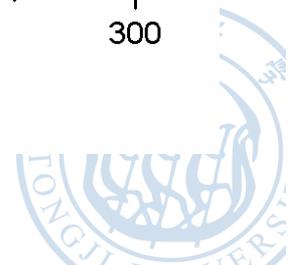
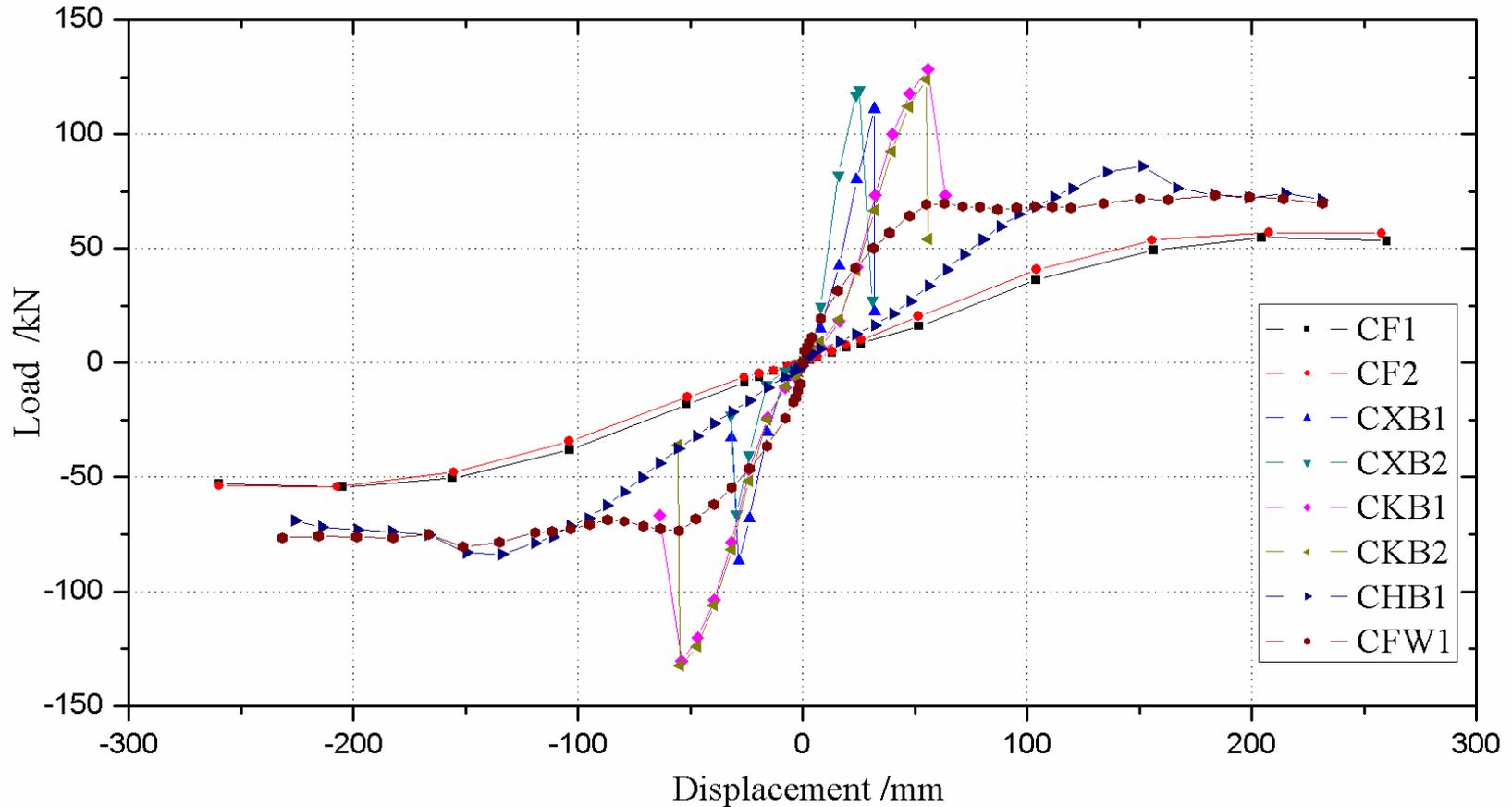
5) **Filling-in light-frame wood shear walls structures perform well in energy dissipation. It is the nails, as dissipative elements, that provide the structure of energy consumption. The hooping effort of the wooden frame maintains the bearing capacity, showing up a good ductility.**

6) **When the unbraced structures, knee-brace structures and filling-in light-frame wood shear walls structures turned to large displacement, the area of the hysteresis curve increased significantly. The reason is that, the splitting of wood releases the elastic strain energy stored in the structures.**



# 4. Experimental results and analysis

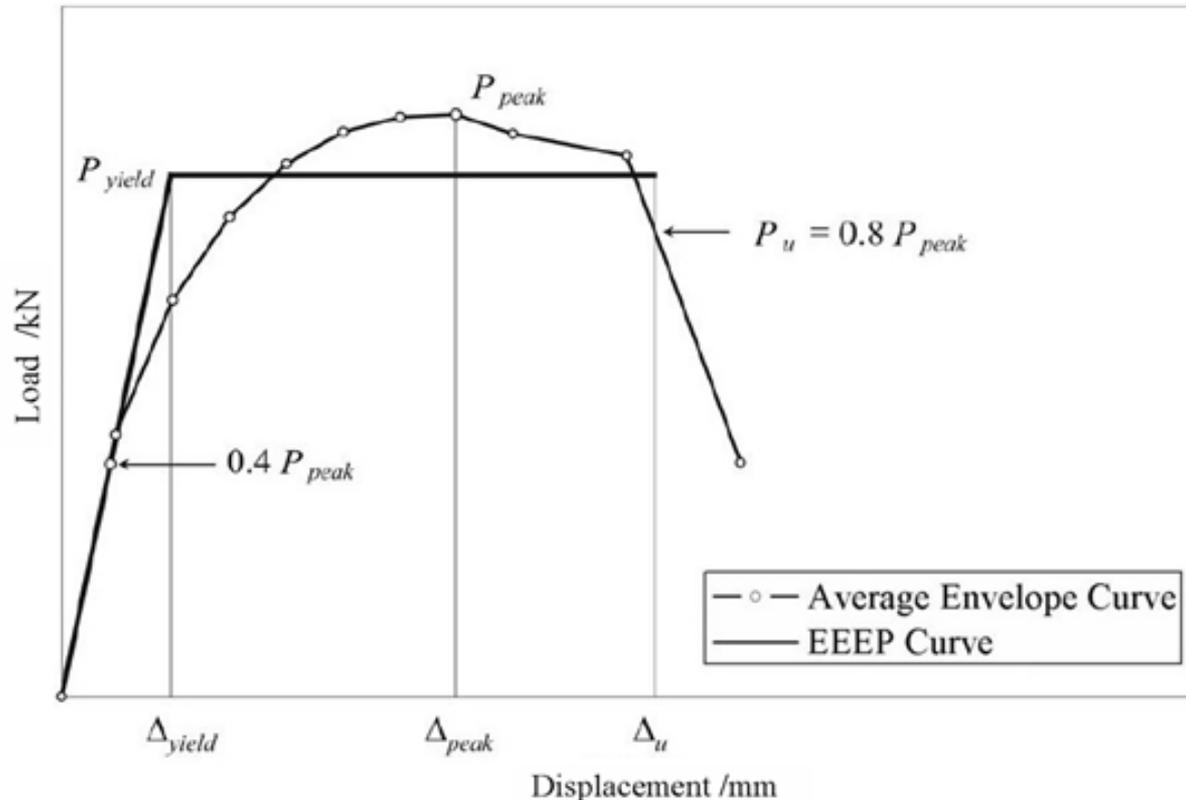
## 4.2 Envelope curves



# 4. Experimental results and analysis

## 4.2 Envelope curves

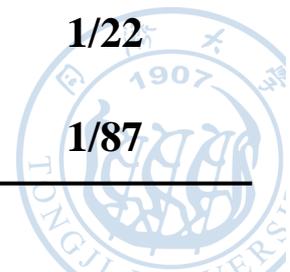
From the envelope curve, the peak load and the relative displacement, the ultimate displacement and the failure load, can be found. The yield point is permitted to be determined using the equivalent energy elastic-plastic curve.



# 4. Experimental results and analysis

## 4.2 Envelope curves

Specimen	$P_{peak}$ /kN	$\Delta_{peak}$ /mm	$P_u$ /kN	$\Delta_u$ /mm	$P_{yield}$ /kN	$\Delta_{yield}$ /mm	$K_e$ / (kN/mm)	$\theta_e$
CF1	54.5	204.7	53.1	260.0	52.8	155.0	0.34	1/18
CF2	55.5	207.5	55.3	258.9	53.7	154.1	0.35	1/18
CXB1	98.9	31.4	27.6	31.9	98.9	31.4	3.15	1/87
CXB2	92.8	29.3	25.2	31.5	92.8	29.3	3.16	1/94
CKB1	129.5	54.8	70.1	63.6	129.4	53.9	2.40	1/51
CKB2	128.1	54.9	45.0	55.8	128.1	54.8	2.34	1/50
CHB1	84.9	142.7	70.3	228.4	78.6	123.6	0.64	1/22
CFW1	76.9	167.4	73.1	231.5	70.8	31.6	2.24	1/87



# 4. Experimental results and analysis

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## 4.2 Envelope curves

Conclusion can be drawn from the envelope curves:

- 1) Unbraced structures are not practical due to the low elastic stiffness. In use it should be supplemented by lateral reinforcement measures.
- 2) According to interstory drift angle tolerance of light wood structure in north America, the value of minor earthquake is 1/100, the value of moderate earthquake is 2/100, and the value of major earthquake is 3/100. From it, the X-brace structures, K-brace structures and the filling-in light-frame wood shear walls structures can meet the general requirements of normal use for building.
- 3) Compared to unbraced structures, the elastic stiffness of knee-brace structures is increased by 83%, while the yield displacement of it is reduced by 20%.



## 4. Experimental results and analysis

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### 4.3 Energy dissipation

**Energy dissipation as an important indicator to measure the structural seismic performance, can be determined by the area of the hysteresis curve.**

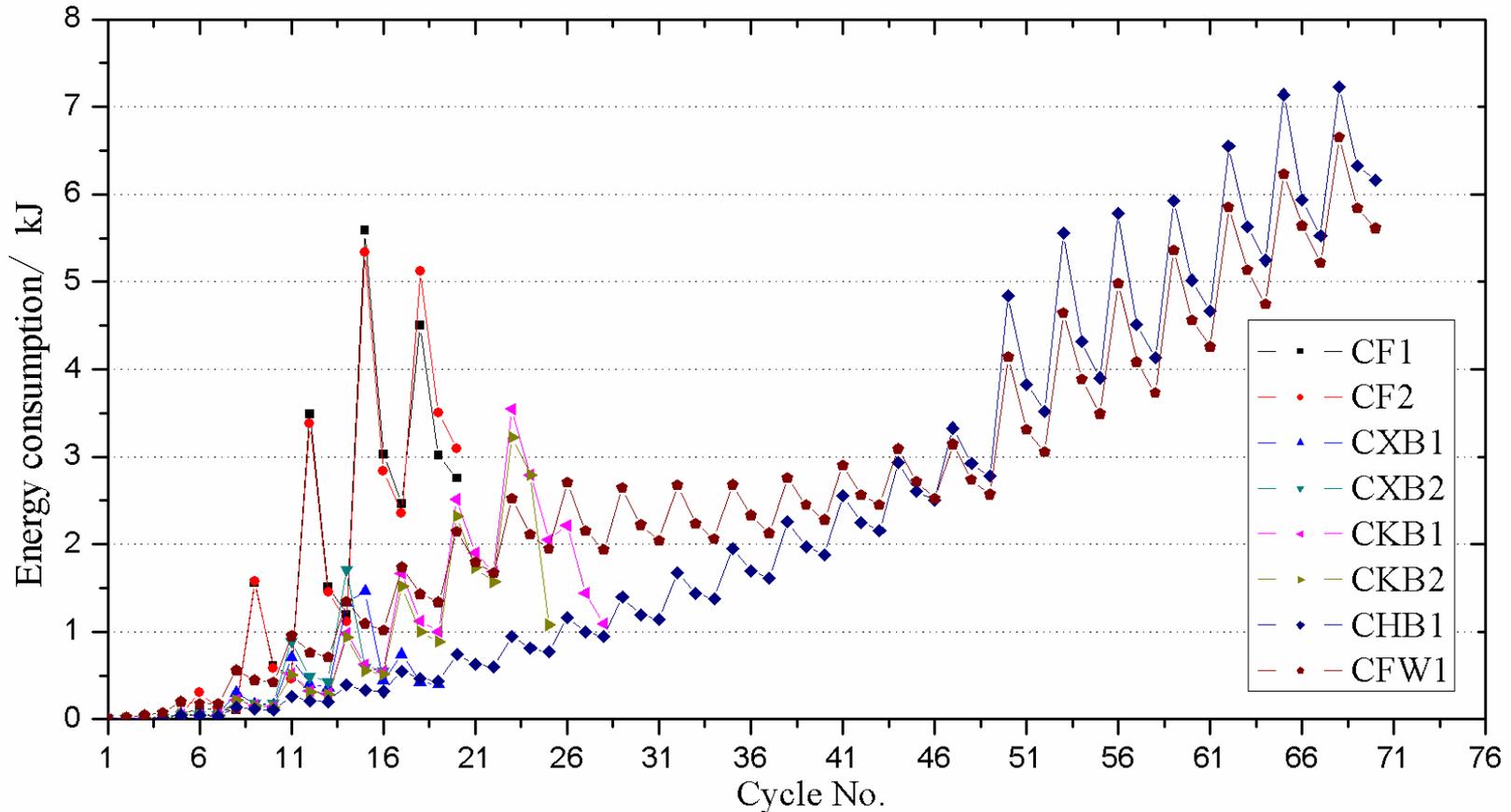
**Friction between components, yield deformation of the bolts and splitting of wood, provide the energy dissipation of the timber post and beam structures.**



# 4. Experimental results and analysis

## 4.3 Energy dissipation

Relation curves of energy consumption and cycles.



# 4. Experimental results and analysis

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## 4.3 Energy dissipation

Conclusion can be drawn from the relation curves of energy dissipation and cycles:

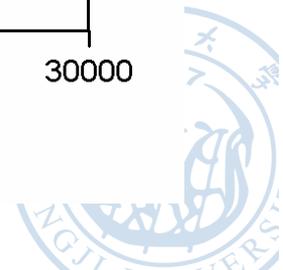
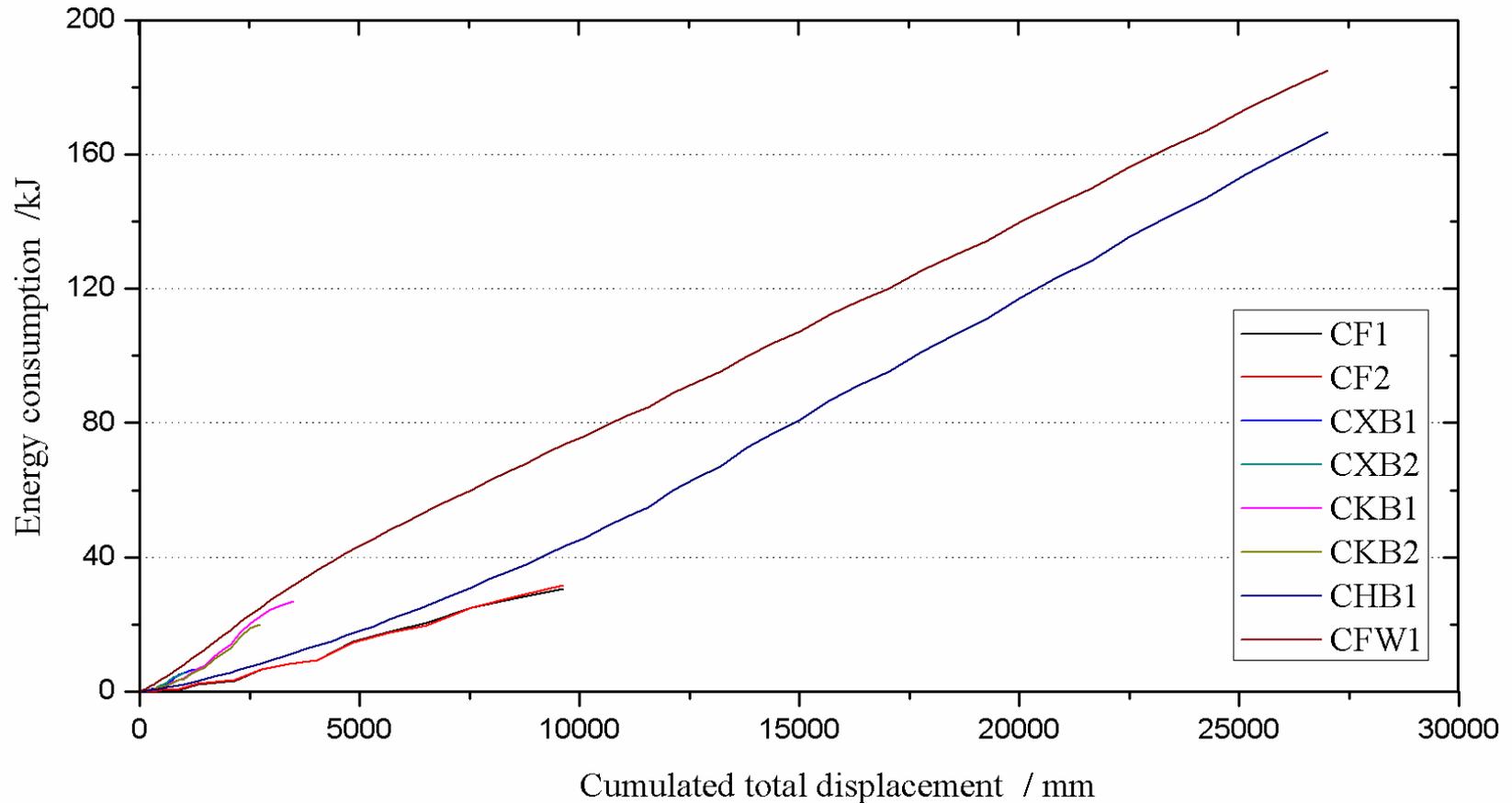
- 1) The peak energy consumption points of X-brace structures and the herringbone-brace structures come earlier because of the brittle failure mode.
- 2) For knee-brace structures and filling-in light-frame wood shear walls structures, larger displacement comes, the better energy dissipation they provide, performing well in the earthquake.
- 3) At the same amplitude, the first cycle has a better energy dissipation than other two cycles. The reason is that, the wood splits when first arriving a large displacement. The wood splitting provides a remarkable energy dissipation in the large displacement.



# 4. Experimental results and analysis

## 4.3 Energy dissipation

Relation curves of the energy consumption and cumulated total displacement.



# 4. Experimental results and analysis

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## 4.3 Energy dissipation

**Conclusion can be drawn from the relation curves of energy dissipation and the total process of lateral displacement:**

- 1) Filling-in light-frame wood shear walls structures have a better energy dissipation capacity than others.**
- 2) Although the X-brace structures and the herringbone-brace structures have a good lateral stiffness, but they do not perform well in energy dissipation due the brittle failure mode.**
- 3) The energy dissipation of the unbraced structures is always lower than others, due to low lateral stiffness.**



**Conclusion can be drawn from the observation of experimental phenomenon and the analysis of the results:**

**(1) The local pressing close, which leads to deformation perpendicular to the grain and splitting, should be considered in the design. The failure mode of the timber post and beam structures shows up the "weak-joint and strong-member".**

**(2) The failure mode of the X-brace structures is that, the tensile element of brace splits. The reason is that, the axial tension stress at the hole, transferred to the tension perpendicular to the grain, leading to splitting. It is necessary to avoid the holes on tension members.**

**(3) Unbraced structures are not practical due to the low elastic stiffness. In use it should be supplemented by lateral reinforcement measures.**

**(4) X-brace structures provide a good lateral stiffness. However, the brace members are too long, that is to say, the buckling is a big problem, and it is hard to deal with intersection joint of the brace members. It is better to use steel tension members instead of the wood ones.**



- (5) **K-brace structures provide a good lateral stiffness. Meanwhile, the brace members are shorter than the ones of X-brace structures and it is easy to deal with the brace joints. However, the structures show low ductility and the failure mode belongs to brittle failure.**
- (6) **Compared to unbraced structures, the elastic stiffness of knee-brace structures is increased by 83%, while the yield displacement of it is reduced by 20%.**
- (7) **The filling-in light-frame wood shear walls structures have better initial stiffness. When most nails have been invalid, the hooping effort of the wooden frame maintained the bearing capacity, showing up a good ductility.**
- (8) **The energy dissipation of the unbraced structures is always lower than others, due to the low lateral stiffness.**



**(9) X-brace structures and K-brace structures do not perform well in energy dissipation due the brittle failure mode.**

**(10) Knee-brace structures show a good energy dissipation capacity. It is the friction between the brace and the wooden frame, that provide the energy dissipation.**

**(11) Filling-in light-frame wood shear walls structures perform well in energy dissipation. It is the nails, as dissipative elements, that provide the energy consumption. When most nails have been invalid, the friction between components provides the subsequent energy dissipation.**



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**Thank you!**

