Seismic Performance of an Innovative Concrete Filled Steel Tubular Truss Bridge

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3. THEORETICAL MODEL
4. THEORETICAL VERSUS EXPERIMENTAL RESULTS
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6. CONCLUSIONS
- **C F S T S t r u c t u r e s**

**C F S T** is a steel-concrete composite structure in which a steel tube is filled with concrete.

1. **Introduction**

**Bosideng Bridge** (L = 530 m, world’s record)

**Millennium Tower, Wien** (H = 202 m, highest building in Austria)
- *CFS T Structures*

Advantages of concrete filled steel tubes (CFST):
- High confinement of the concrete
- Delay of the steel local buckling
- High compressive and flexural strength

Earthquake and Fire Resistance
Rapid and easy construction
Savings in construction costs

Application of truss typology in bridges

Truss typology is adopted for nearly all the arch ribs of steel and CFST bridges. Compared with steel arch bridges, CFST arch bridges are considered to be more economical.

1. Introduction

Cross-section types of CFST arch rib

- Single tube
- Dumbbell type
- Truss type
- **CFST Structures**

All the cross-sections of the ribs of the top 5 longest CFST arch bridges are truss type. CFST trusses can be also applied for the pillar of deck arch bridges. Mendon Bridge is the first to realize the CFST truss of specific stress.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Name</th>
<th>Span (m)</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bosideng Bridge</td>
<td>530</td>
<td>2012</td>
</tr>
<tr>
<td>2</td>
<td>Wushan Bridge</td>
<td>460</td>
<td>2005</td>
</tr>
<tr>
<td>3</td>
<td>Zhijinghe Bridge</td>
<td>430</td>
<td>2009</td>
</tr>
<tr>
<td>4</td>
<td>Liancheng Bridge</td>
<td>400</td>
<td>2008</td>
</tr>
<tr>
<td>5</td>
<td>Maoaojie Bridge</td>
<td>368</td>
<td>2006</td>
</tr>
</tbody>
</table>

### 1. Introduction

Seismic Performance of an Innovative Concrete Filled Steel Tubular Truss Bridge

- **Mendon Bridge**
- **Bosideng Bridge**
- **Wushan Bridge**
- **Zhijinghe Bridge**
- **Liancheng Bridge**
- **Maoaojie Bridge**
The object of this research is Ganhaizi Bridge, located in a very high intensity seismic region (Sichuan Province, China), one of the most unusual viaducts that have been recently built. It has a total length of 1811 m, and the innovative structural typology is characterized by adopting steel tubes for nearly entire structure. Due to the favorable ductility of CFST materials and lightweight truss structure, a good earthquake behavior is expected.

1. Introduction

View of Ganhaizi Bridge
- **Ganhai zi Bridge**

The bridge has a total length of 1811 m, with longitudinal slope 4%, composed of three continuous units, separated by 400 mm width joints.

The span arrangement is:
- The first units with 11 spans ($L_{tot} = 563.3$ m):
  40.7 m + 9 × 44.5 m + 40.7 m

- The second units with 19 spans ($L_{tot} = 1044.70$ m):
  45.1 m + 3 × 44.5 m + 11 × 62.5 m + 3 × 44.5 m + 45.1 m

- The third units with 6 spans ($L_{tot} = 268.2$ m):
  45.1 m + 4 × 44.5 m + 45.1 m

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**1. Introduction**

Seismic Performance of an Innovative Concrete Filled Steel Tubular Truss Bridge

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**Evaluation layout of Ganhai zi Bridge (Unit: cm)**

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b) The second units
The superstructure is as following: a) concrete deck, b) steel truss web, c) CFST bottom chord. The typical cross section of the truss girder is 440 cm height. The bottom chord tubes are CFST with a diameter of 813 mm and thickness from 18 mm to 32 mm, filled with C60 concrete. The web steel tubes have a diameter of 406 mm.

1. Introduction

Seismic Performance of an Innovative Concrete Filled Steel Tubular Truss Bridge
- Ganhaizi Bridge

Three types of piers have been used:

(a) \( H < 25 \text{ m} \)
Reinforced concrete (RC) double column piers.
(Pier number: 1, 10-13, 31-35)

(b) \( 25 \text{ m} < H < 90 \text{ m} \)
CFST truss piers.
It is generally composed of four CFST columns connected together by steel truss tubes.
The CFST columns have a diameter of \( 720 \text{ m} \), with wall...
H > 90 m
CFST composite pier (the tallest one is 107 m).
The truss tubes are replaced with 40 cm thick RC plates at the bottom region of 30 m height to improve its rigidity. The CFST columns have a diameter of 813 mm, a wall thicknesses...
Construction phases of Ganhaizi Bridge

1. Introduction

Seismic Performance of an Innovative Concrete Filled Steel Tubular Truss Bridge
Construction phases of Ganhaizi Bridge

1. Introduction

CFS T piers ($H_{\text{max}} = 107\, \text{m}$)
Construction phases of Ganhaizi Bridge

1. Introduction

Seismic Performance of an Innovative Concrete Filled Steel Tubular Truss Bridge
- Shaking Table Tests

Based on the high pier zone of real bridge as prototype, a shaking table test with two span and three piers was designed and performed in Fuzhou University. Subjected to the restrictions of length and bearing capacity of test device, the geometric scale ratio was chosen as 1:8. The specimen height was 13.9 m (H_real_pier = 107 m) with total mass 20.9 t.
- **Shaking Table Tests**
  - 30 accelerometers,
  - 8 displacement transducers:
  - 60 strain gages, including longitudinal, transverse and vertical directions.

### Instrumentation arrangement details

**Seismic Performance of an Innovative Concrete Filled Steel Tubular Truss Bridge**

![Instrumentation arrangement diagram](image-url)
<table>
<thead>
<tr>
<th>Quantity</th>
<th>Dimension</th>
<th>Scaling law</th>
<th>Scale factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear Length</td>
<td>$S_l$</td>
<td>[L]</td>
<td>1/8</td>
</tr>
<tr>
<td>Displacement</td>
<td>$S_l$</td>
<td>[L]</td>
<td>1/64</td>
</tr>
<tr>
<td>Elastic modulus</td>
<td>$S_E$</td>
<td>[E]</td>
<td>1</td>
</tr>
<tr>
<td>Strain</td>
<td>$S_\varepsilon$</td>
<td>--</td>
<td>1/8</td>
</tr>
<tr>
<td>Density</td>
<td>$S_\rho$</td>
<td>[$\rho$]</td>
<td>1</td>
</tr>
<tr>
<td>Axial force</td>
<td>$S_N$</td>
<td>[E L^2]</td>
<td>1/256</td>
</tr>
<tr>
<td>Bending moment</td>
<td>$S_M$</td>
<td>[E L^3]</td>
<td>1/2048</td>
</tr>
<tr>
<td>Acceleration</td>
<td>$S_a$</td>
<td>[E $\rho^{-1}$ L^{-1}]</td>
<td>1</td>
</tr>
<tr>
<td>Frequency</td>
<td>$S_\omega$</td>
<td>[E $0.5 \rho^{-0.5}$ L^{-1}]</td>
<td>8</td>
</tr>
<tr>
<td>Time</td>
<td>$S_T$</td>
<td>[E $-0.5 \rho^{0.5}$ L]</td>
<td>1/8</td>
</tr>
</tbody>
</table>

**2. Shaking Table Tests**

Seismic Performance of an Innovative Concrete Filled Steel Tubular Truss Bridge
A three-dimensional FEM was developed in OpenSees. The main mechanical components of piers, such as circular CFST columns and slant supports, were modeled using nonlinear beam-column elements with discrete fiber section model in OpenSees. Remaining components were simulated using elastic beam-column elements.

**Material models**

a) G iuffre-M enegotto-Pinto model

b) Liang & Fragomeni model for seismic performance of an innovative concrete filled steel tubular truss bridge
- Modal parameters

Frequencies are close to theoretical frequency ratio of 1:8, and modal shapes are also the same, which demonstrates the accuracy of similarity relationship.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Real bridge (1)</th>
<th>Modal Shape (FE analysis)</th>
<th>Specimen (2)</th>
<th>Modal Shape (2)/(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.194 Hz</td>
<td></td>
<td>1.45 Hz</td>
<td>1:7.47</td>
</tr>
<tr>
<td>2</td>
<td>0.274 Hz</td>
<td></td>
<td>2.10 Hz</td>
<td>1:7.66</td>
</tr>
</tbody>
</table>

Fundamental frequency comparison between real bridge and specimen.

<table>
<thead>
<tr>
<th>Order</th>
<th>Real bridge (1)</th>
<th>Full mass FEM (3) (3)/(1)</th>
<th>Theoretical value</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.194 Hz</td>
<td>0.526 Hz</td>
<td>1:2.71</td>
<td>1:2.82</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>0.274 Hz</td>
<td>0.803 Hz</td>
<td>1:3.64</td>
<td>1:2.82</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>
4. Results

Comparison of displacement time histories

- Transverse excitation
  - Top of the pier
  - Comparison of displacement time histories

- Longitudinal excitation
  - Seismic Performance of an Innovative Concrete Filled Steel Tubular Truss Bridge

a) Transverse excitation

b) Longitudinal excitation
- **Vertical Strains**

Comparisons of vertical strains envelope between experimental and theoretical results

![Diagram showing vertical strains comparison](image)

a) Transverse excitation  
b) Longitudinal excitation

**4. Results**

Comparison of vertical strain envelope

Seismic Performance of an Innovative Concrete Filled Steel Tubular Truss Bridge
- Bi-directional excitations

(a) vertical strains under transverse excitations are larger than under longitudinal direction at the same intensity level (PGA = 0.22 g) and comparable to bi-directional excitations.

(b) the same phenomenon could be found for displacement.

It seems not to be necessary to consider the influence of bi-directional excitations for this bridge.

4. Results Comparison Seismic Performance of an Innovative Concrete Filled Steel Tubular Truss Bridge
- **Ground motions influence**

Following the Design Specification for Highway Bridges (Japan Road Association), Bridges with complex dynamic responses should be checked for intensive ground motions (earthquakes with low probability to occur) using two kinds of ground motions:

**a) Type 1. Plate boundary type of earthquakes with a magnitude of around 8:**

**b) Type 2. Inland type of earthquakes with a magnitude of around 7-7.2 at very short distance.**

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5. **Influence of ground motion.**

Seismic Performance of an Innovative Concrete Filled Steel Tubular Truss Bridge
- A. Accelerations

The acceleration envelope results show that under longitudinal or transverse seismic excitations, acceleration due to Type 2 ground motions are significantly larger than due to Type 1 ground motions. It means that when subjected to a strong ground motions within short distance, the column can increase the acceleration response through remarkable oscillation on the lattice column zones, which reduces acceleration on the deck.

5. Influence ground mot.
- **B. Displacements**

- Under longitudinal and transverse directional excitations, displacements due to Type 2 ground motions are smaller than due to Type 1 ground motions.

- Displacement at the top of pier under T111 is larger than under T213.

- **Longitudinal direction**

  a) Longitudinal

  ![Longitudinal Displacement Graph](image1)

  b) Transverse direction

  ![Transverse Displacement Graph](image2)

5. **Influence ground m o t.**
# C. Strains

a) **Transverse direction.** Strain envelope values reduce from bottom to up.

b) **Longitudinal direction.** Strains at the position of slant support and top of RC web are larger than other positions. The slant support shares the internal force, protect the top connection between the CFST column and girder. Subjected to strong ground motions of Type 1 and Type 2, the pier strain is in elastic range.

![Normalized strain envelope at the extreme edge of steel tubes](image)

5. **Influence ground motion.** Seismic Performance of an Innovative Concrete Filled Steel Tubular Truss Bridge
Conclusions

Through white noise excitation, the identified fundamental frequency of structure is 1.45 Hz in longitudinal direction and 2.10 Hz in transverse direction. The frequency ratio between prototype and model is 1:7.47 in the first order and 1:7.69 in the second order, which are closed to theoretical frequency ratio of 1:8. According to the similitude relationship, displacement of specimen agrees well with prototype.

Under bidirectional excitations, displacement and strain are not larger than subjected to one directional seismic input. Hence, it seems not necessary to consider the influence of bidirectional excitations.

The accuracy of FEM approaches is verified through comparisons of fundamental frequency.
- Influence of ground motions are investigated with two types of seismic records, results show that Type 1 (Plate boundary type of earthquakes with a magnitude of around 8) earthquakes generate larger responses than Type 2 (Inland type of earthquakes with a magnitude of around 7-7.2 at very short distance) earthquakes in displacement and strain of column, while the acceleration subjected to Type 2 earthquakes are significantly larger than subjected to Type 1 earthquakes.

- Subjected to strong ground motions of Type 1 and Type 2, the structure remains in elastic range.
Thank you, Teşekkür ederim
Grazie, 谢谢

6. Conclusions
Seismic Performance of an Innovative Concrete Filled Steel Tubular Truss Bridge