2014 CMTS-TRB Conference: Innovative Technologies for a Resilient Marine Transportation System

Composite Anti-collision Bumper System for Bridge

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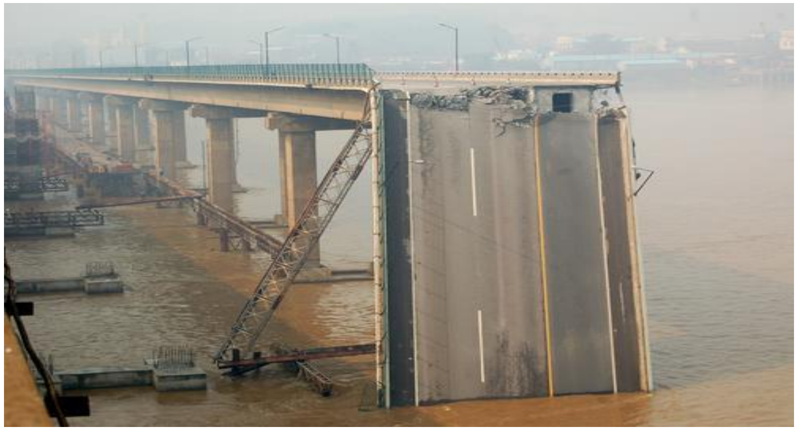
Ⅰ. Composite Anti-collision System for Bridge

Typical Ship-bridge Collision Accidents

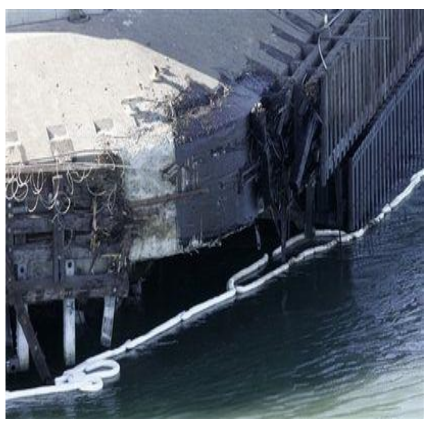


June 15, 2007, Guangdong Jiujiang bridge, **the bridge was collapsed.**

→ **bridge collapse**

June 6, 2011, Wuhan Yangtze river bridge, **bow was a huge gap.**

→ **ship damaged**



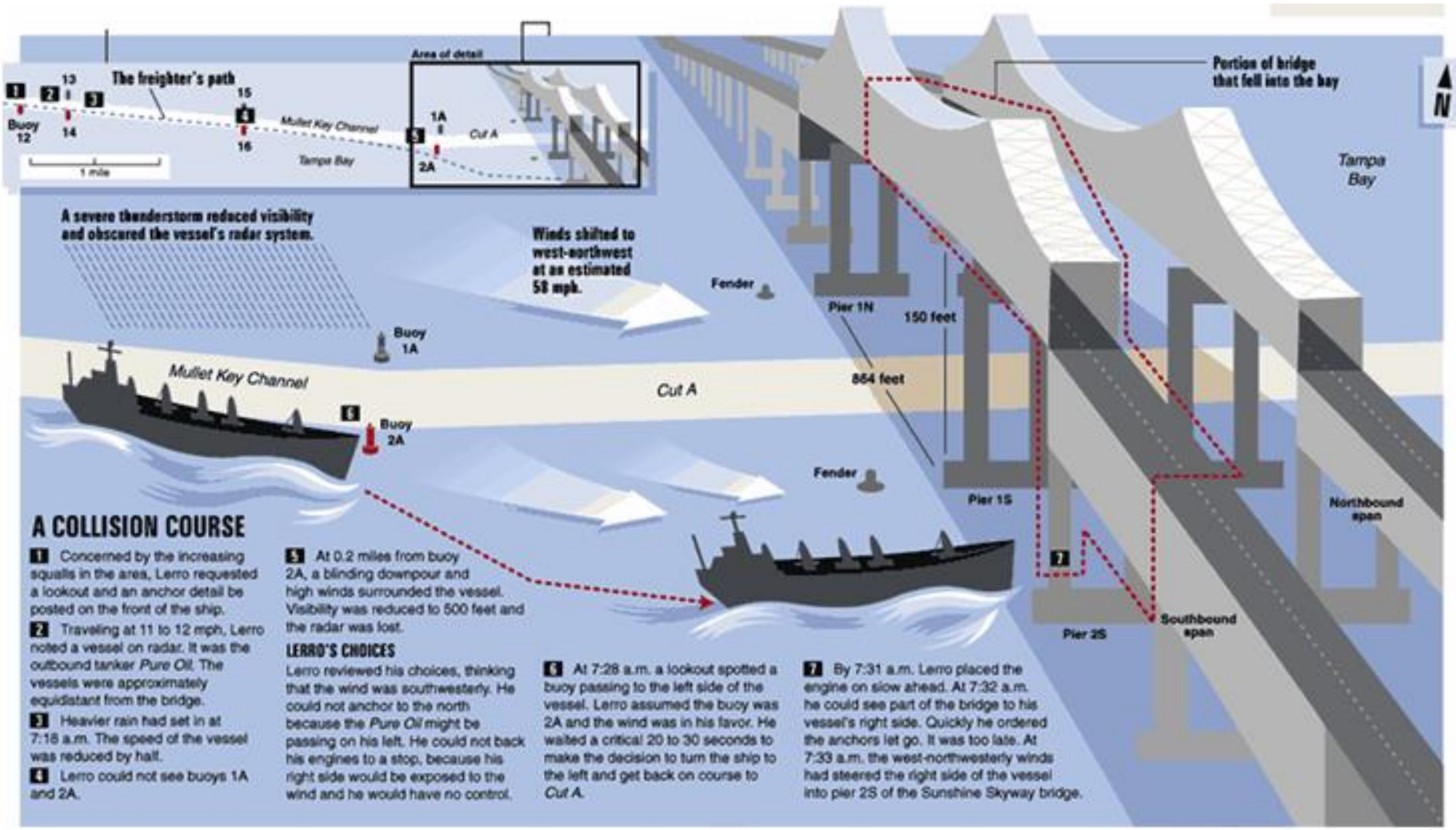
2007, Freighter San Francisco bridge (USA), **220000 litres of oil leakage.**

→ **polluted water**

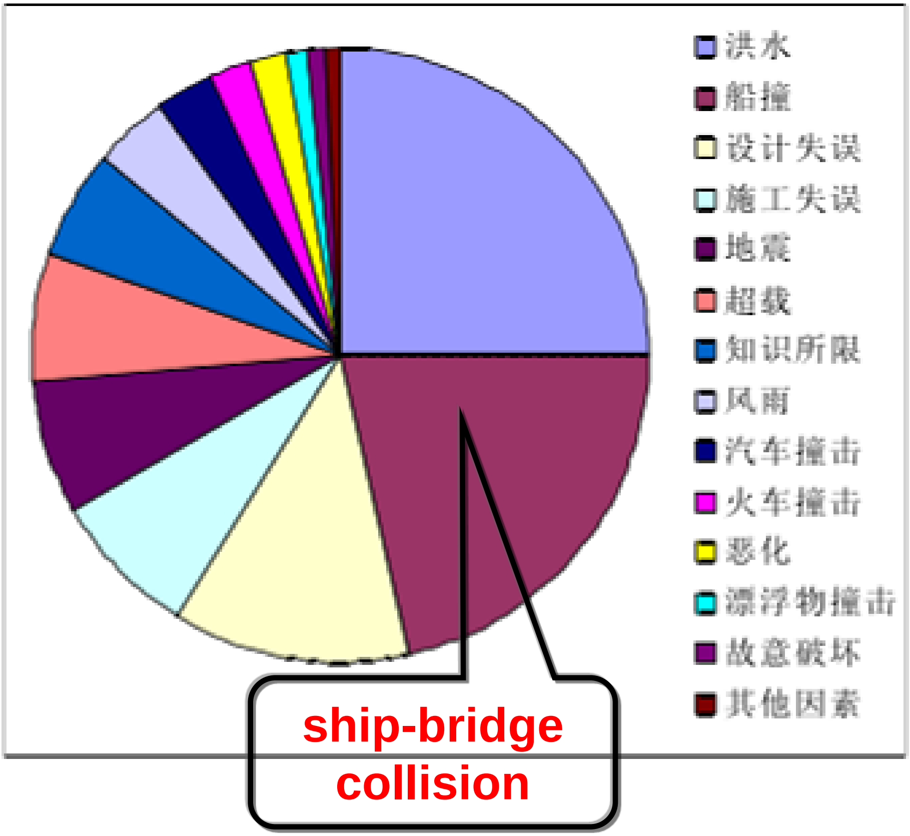
May 13, 2012, Yueyang Pingjiang fangu bridge, **at least 6 people missing.**

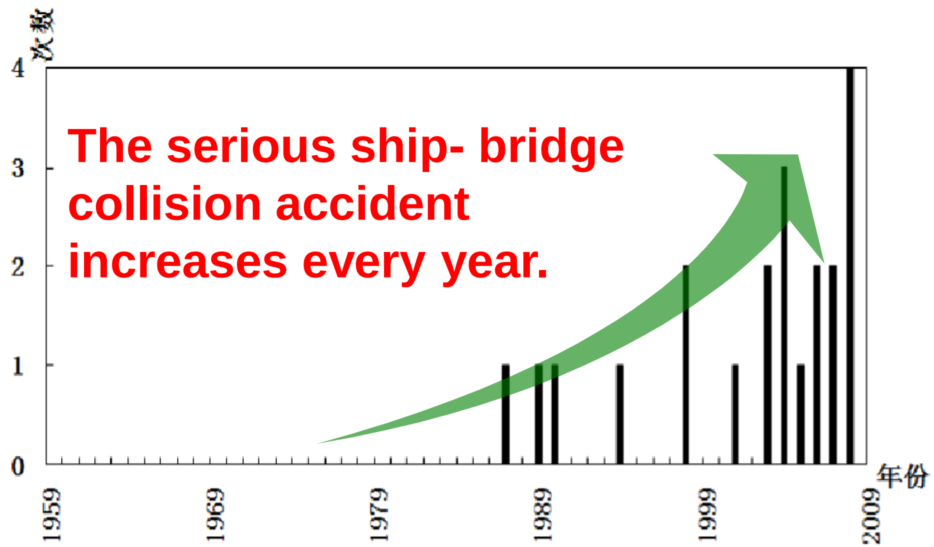
→ **casualties, channel suffocate**

Sunshine Bridge was collapsed by 35000 dwt bow



Typical Ship-bridge Collision Accidents





Ship-bridge collision accidents become an important factor of the bridge damaged.

The problems need to solve:

For new bridge: impact calculation and installation of bridge collision avoidance system;

For old bridge: review on bearing capacity and strengthen the ability against collision.

The Existing Bridge Collision Avoidance Systems

1. Sand cofferdam protection method

Sunshine Skyway Bridge

- **Large** overall quality ;
- **Simple** construction ;
- **Less** maintenance.

2. Fender pier piles method

Jingzhou Yangtze River Highway Bridge

- Composed of **piles group**;
- Suitable for **small energy impact**;
- Difficult to repair after the damage;
- **￥6300 million**

The Existing Bridge Collision Avoidance Systems

3. Artificial island method

- ◆Suitable for high energy impact by large ships;
- ◆Not suitable for unfavorable geological conditions of bridge;
- ◆Not conducive to the normal use of channel;
- ◆nearly ￥100 million

4. Buffer materials facilities method

- ◆Main materials: wood, rubber, and other buffer materials;
- ◆Suitable for small ships impact;
- ◆The life aging of the rubber: about ten years

The Existing Bridge Collision Avoidance Systems

5. Buffer facility engineering method

Richmond-San Rafaei bridge (USA)

Around the piers which were easy to hit, wooden truss structure buffer facilities were set.

6. Steel cofferdam and fixed steel box method

Pingtan bridge (old)

- ◆Applicable to the cap, not apply to the pier ;
- ◆Need to take anti-corrosion measures to prolong the life of steel (20 years);
- ◆￥6000 million

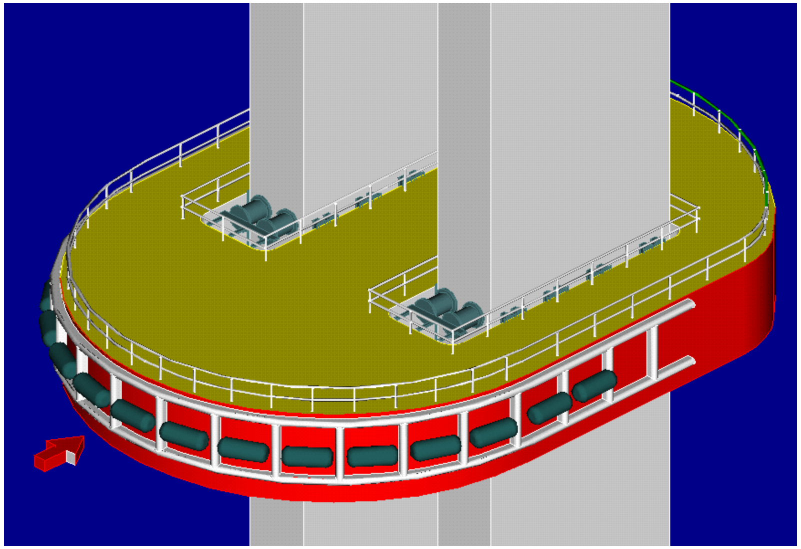
The Existing Bridge Collision Avoidance Systems

7. The steel rope rubber ring method

The Zhanjiang Bay Bridge

- ◆This system has a good protective effect In the sham condition;
- ◆Can aside from the bow direction

8. Floating steel sleeve box for energy dissipation method



Huangshi Yangtze River Bridge

- ◆Composed of steel and rubber parts ;
- ◆Currently implemented the biggest impact resistance capacity of the floating box is 3000 ton ship;
- ◆￥100 million

Research on Composite Anti-Collision System

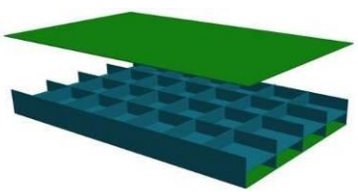
The problems of traditional anti-collision system

◆ **Easily damaged**, **usually single impact**, difficult to repair the damaged anti-collisionsystem;

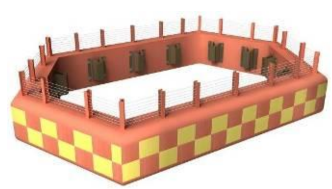
◆ The **ship is vulnerable to injury**;

◆ Steel is **easy to rust** in alternating wet and dry environment, thus **the cost of maintenance is high**.

New-type anti-collisionsystem



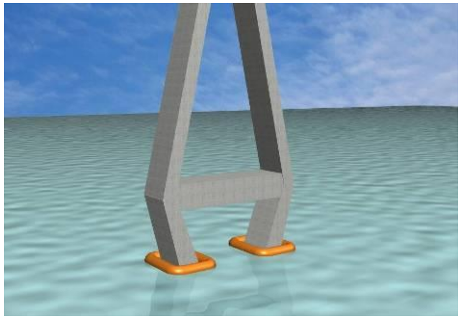
Web-reinforced sandwich composites



Composite bridge collision avoidance system

Self-floating type

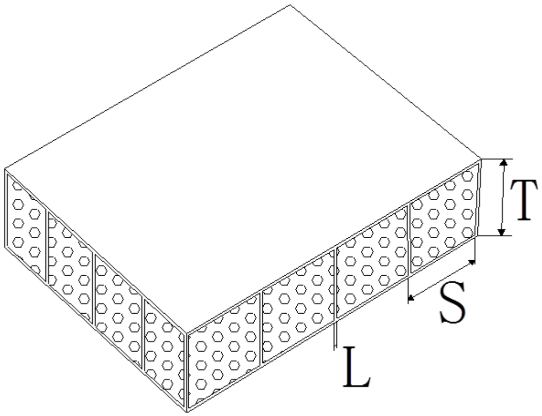
Fixed type

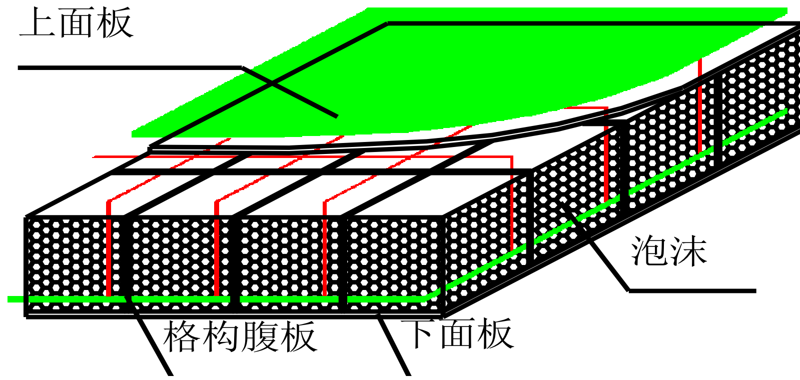


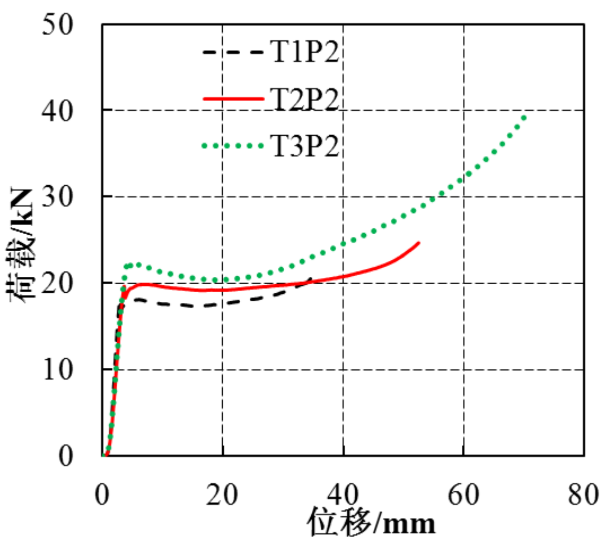
Cylinder-shaped

Quasi-static Compression Tests of Web-reinforced FRP-foam Sandwich Composites

Critical bearing capacity and energy absorption of web-reinforced sandwich composites





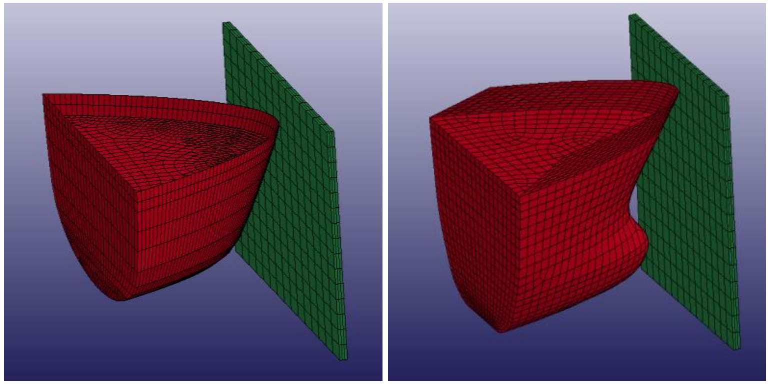


- **Primary and secondary relation of the factors:**

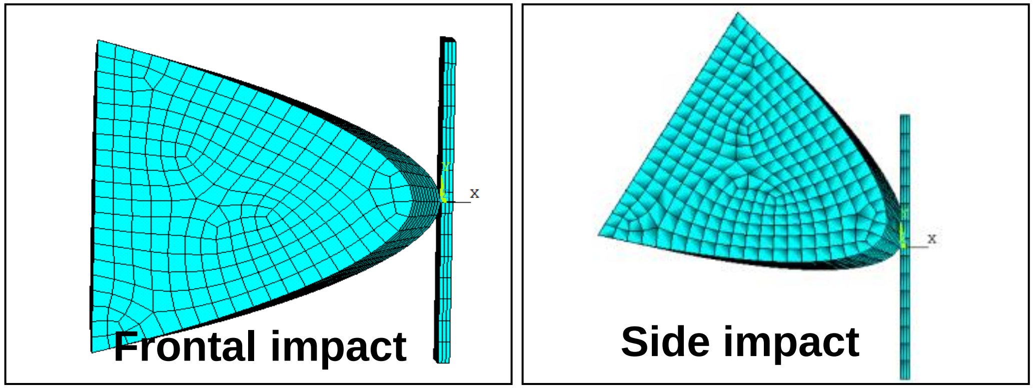
lattice layer thickness (L) > lattice spacing (S) > height of specimen (T)

Theorical Study of Composite Anti-Collision System

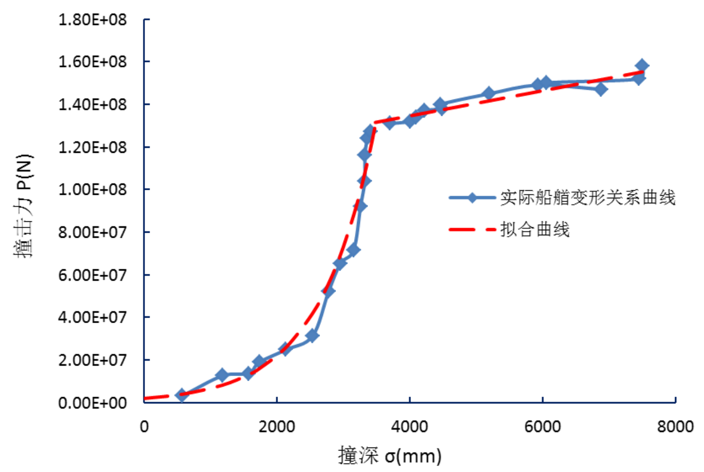
Different types of bow



Different impact conditions



- **Nonlinear static analysis**

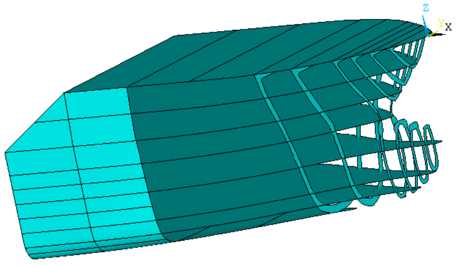


Modeling of bow stiffness

$$F = \begin{cases} a \cdot b^{x} & \text{Load period} \\ cx + d & \text{Unload period} \end{cases}$$

Parameter fitting

$$F = \begin{cases} 2E+06 \cdot e^{0.0011x} \\ 5900x + 1.11E+08 \end{cases}$$

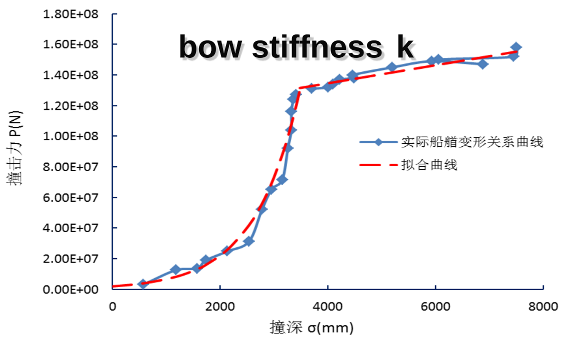


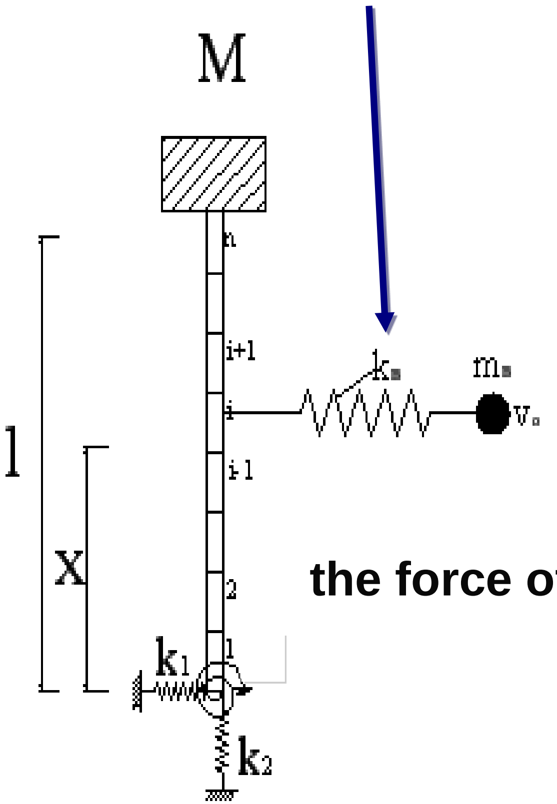
5000 DWT bow

The stiffness of bow

DWT (t)	Stiffness（MN/m）
500	5.0
1000	6.5
2000	10.0
3000	15.0
5000	16.0
10000	20.0
50000	22.5

Theorical Study of Composite Anti-Collision System





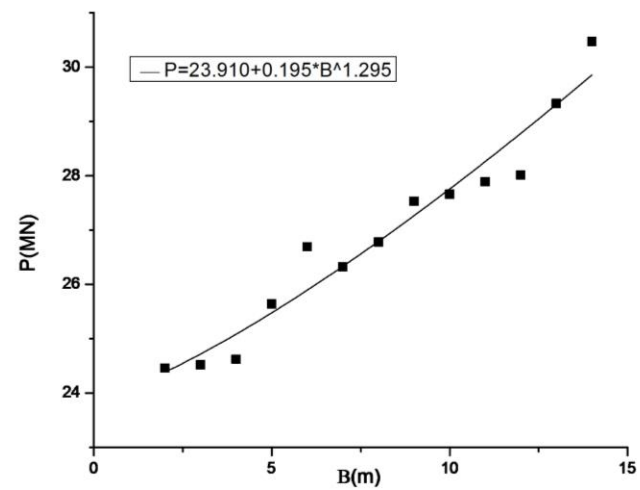
Established **dynamic equation** of the pier impacted by the ship considering the following factors:

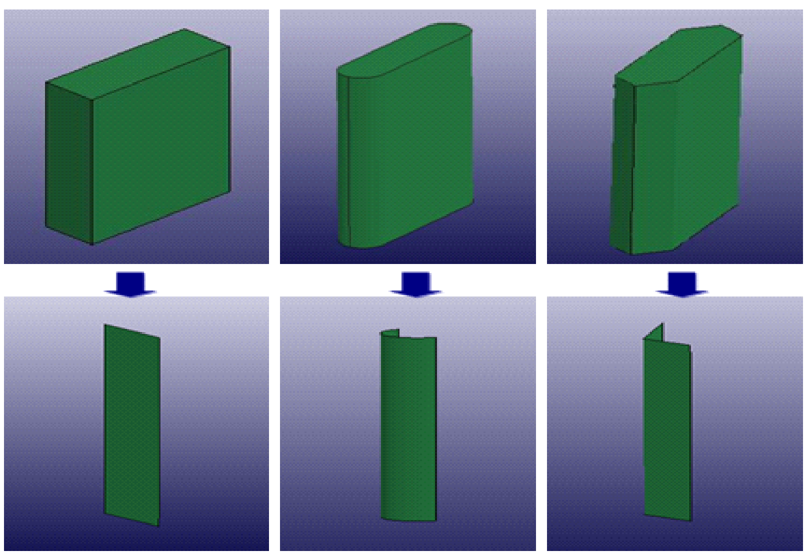
- Transfer the impact system into **the transverse vibration system with initial velocity**;
- The ship and the pier **as a whole vibration system**;
- Divide the pier as **n units along the pier high-direction**;
- Each unit **as a Timoshenko beam**.

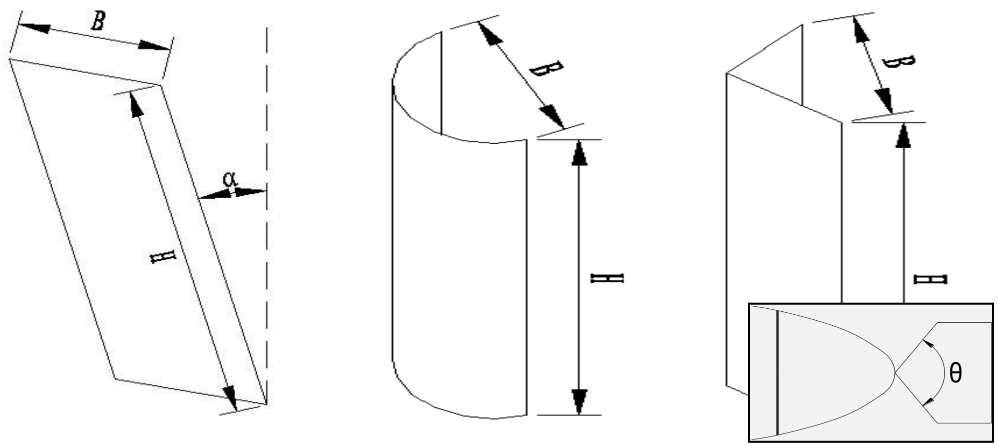
the force of ship:

$$f(t) \approx \frac{e^{at}}{T}\left\{-\frac{1}{2}\mathrm{Re}\left[F(a)\right]+\sum_{k=0}^{N}\mathrm{Re}\left[F\left(a+i\frac{k\pi}{T}\right)\right]\cos\left(\frac{k\pi}{T}\right)t -\sum_{k=1}^{N}\mathrm{Im}\left[F\left(a+i\frac{k\pi}{T}\right)\right]\sin\left(\frac{k\pi}{T}\right)t\right\}$$

The force based on the shape of pier





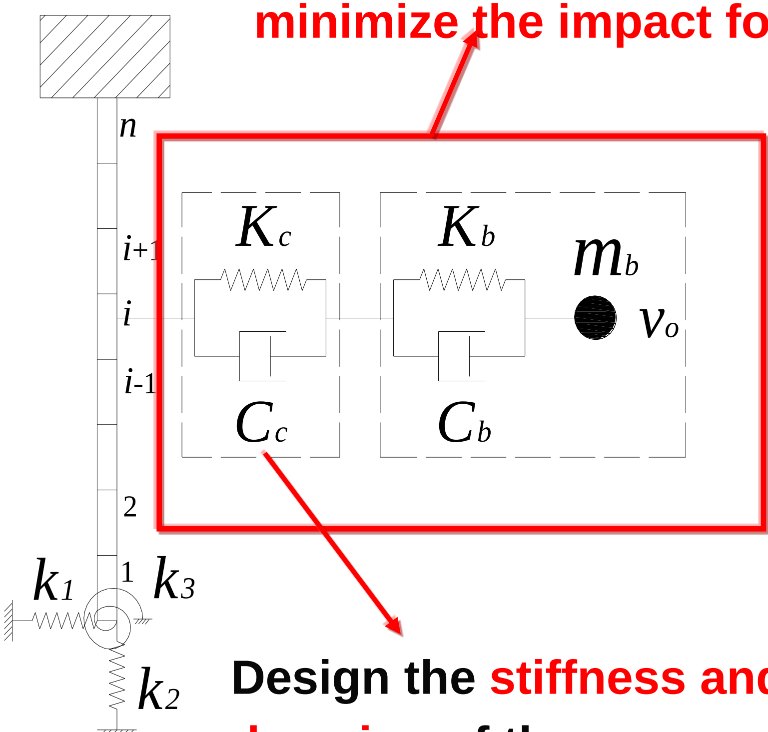


rectangle Round end tip section

Impact system in Nanjing Tech (230000J)

Horizontal test

Optimization Design of Composites System



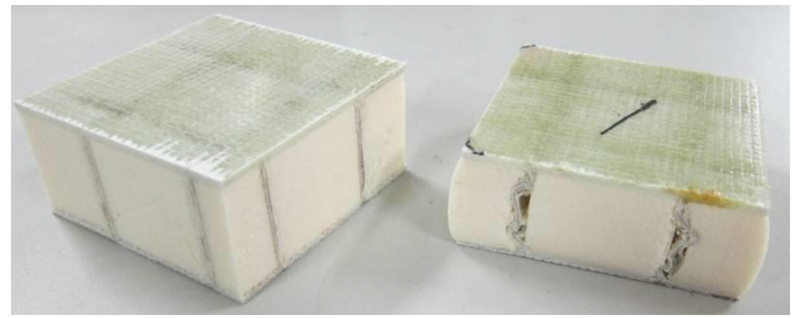
Optimization objective：
minimize the impact force

Design the stiffness and damping of the composites anti-collision system

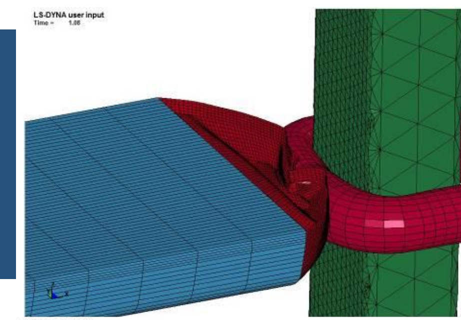
⇩

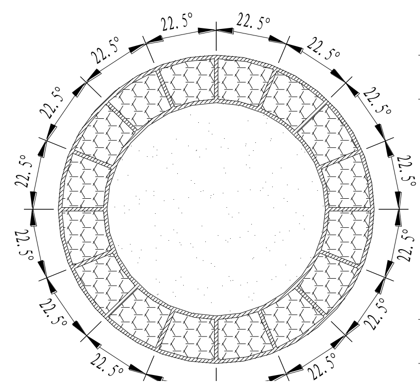
Design the components and structure

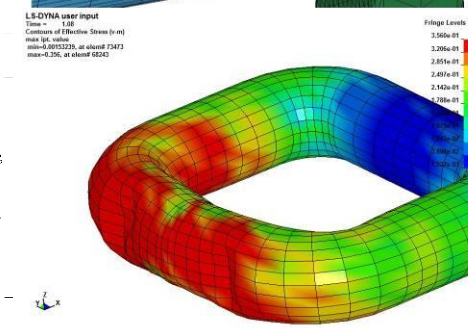
Web-reinforced FRP-foam Sandwich Composites



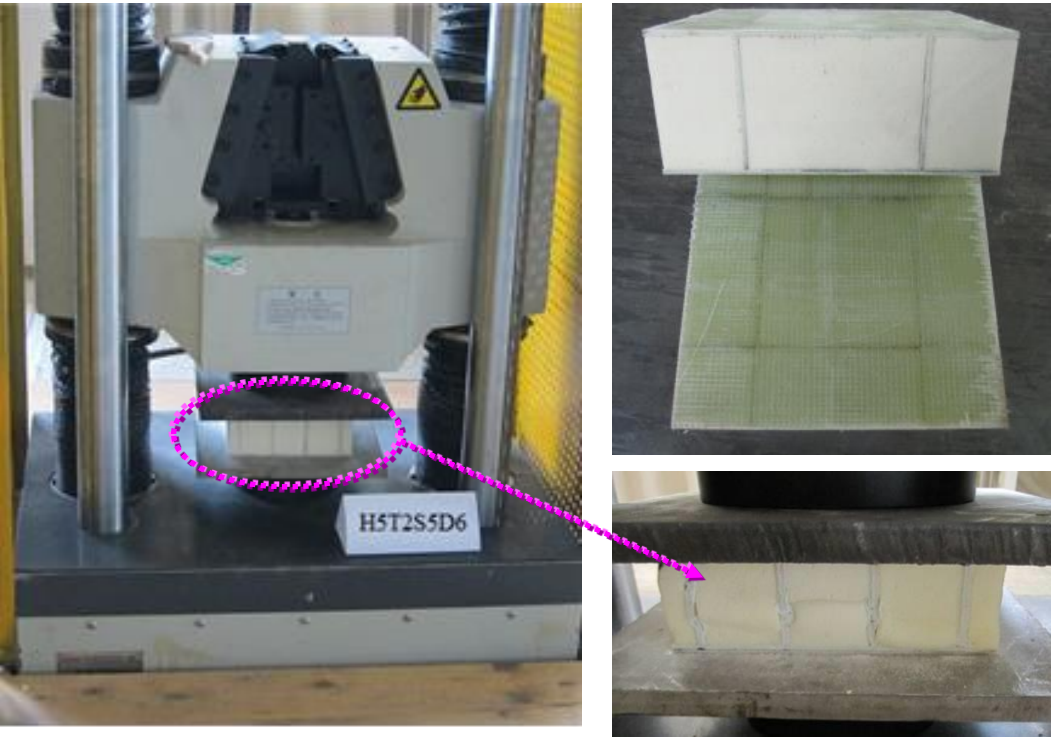
Cylinder Web-reinforced FRP-foam Sandwich Composites







Energy absorbsion of Web-reinforced FRP-foam Sandwich Composites



Test mode

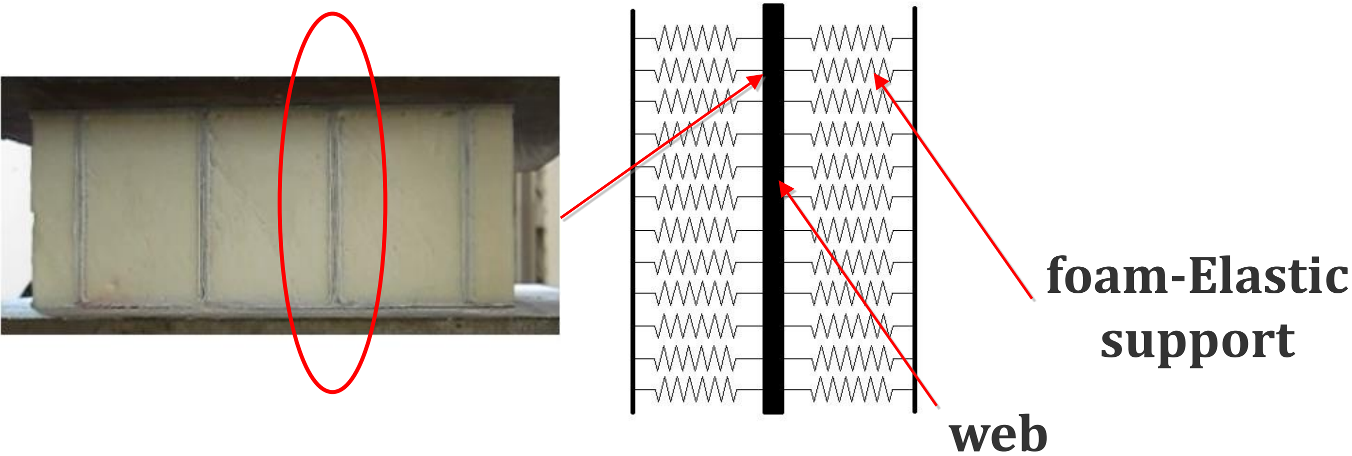
Elastic stage

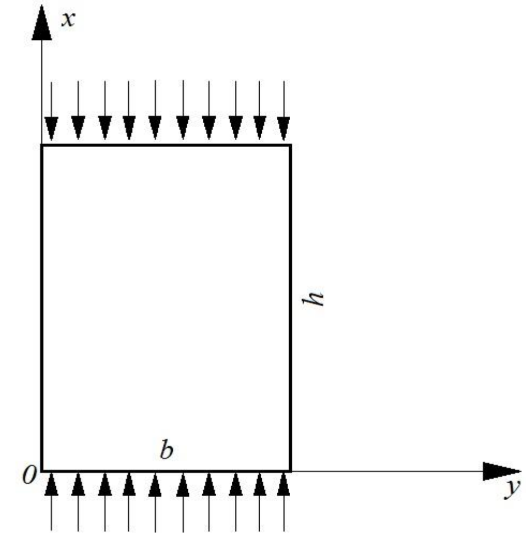
After the yield stage

foam pressure dense phase

failure mode

Lattice web compression buckling analysis





Web deformation energy

$$U_1 = \frac{D}{2}\iint \left\{ \left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} \right)^2 - 2(1-v) \left[\frac{\partial^2 w}{\partial x^2}\frac{\partial^2 w}{\partial y^2} - \left(\frac{\partial^2 w}{\partial x \partial y} \right)^2 \right] \right\}$$

External work

$$U_2 = \frac{1}{2}\iint \left[N_x \left(\frac{\partial w}{\partial x} \right)^2 + 2N_{xy}\left(\frac{\partial w}{\partial x}\frac{\partial w}{\partial y} \right) + N_y \left(\frac{\partial w}{\partial y} \right)^2 \right] d_x d_y$$

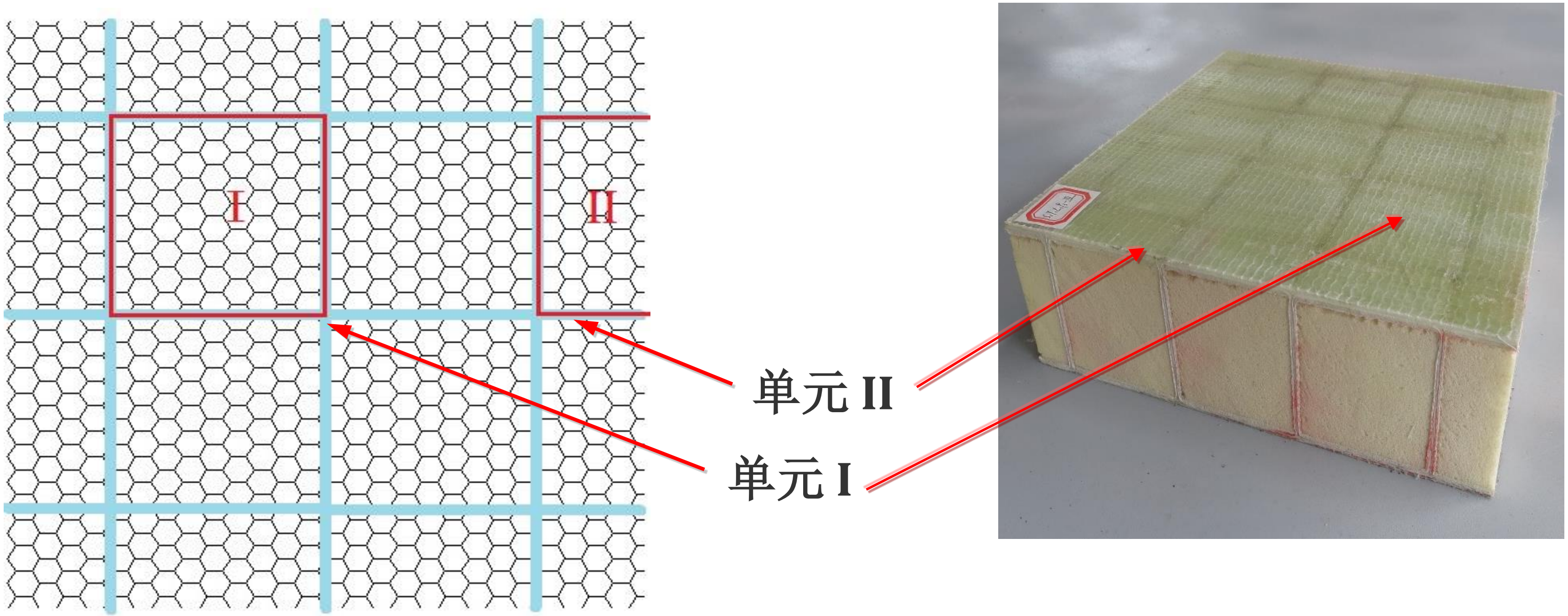
$$U_3 = \frac{1}{2}\iint k w^2 \, d_x d_y$$

Total Web deformation energy

$$E = U_1 + U_2 + U_3$$

$$\frac{\partial E}{\partial A_{mn}} = 0$$

Lattice web compression strength analysis



unit I

$$P_{c,\,pre} = 0.85 f_F' A_F + f_W A_W$$

unit II

$$P_{u,\,pre} = f_W A_W$$

Ultimate strength

$$P_{pre} = \sum P_{c,\,pre} + \sum P_{u,\,pre}$$

Project Examples of Composite Anti-Collision System

- **Designed the Innovative composite bridge anti-collision system;**
- **Related technology won 2 international PCT patents and 5 related national patents authorization.**

Projects completed design and Passed reviews

- Fuzhou Wulong River Bridge
- Changzhou Xinmengge Bridge
- Guangzhou-Shenzhen High-speed Way Along The Yangtze River Bridge (Shenzhen section)
- Hongkong, Zhuhai and Macao Bridge
- The North Bridge of Runyang Bridge
- LangQi Min River Bridge
- PinTan Railway Bridge
- Huanggang Yangtze River for Public Railway And road
- Yangtze River Second Branch Bridge
- Tonglin Yangtze River Bridge for Public Railway and Road
- 。。。 More than 100 Bridge


证书号第736586号

发明专利证书

发明名称：自浮式复合材料桥梁压水防撞装置

发明人：庄勇；刘伟庆；张广；王应良；方海；陆伟东

专利号：ZL 2009 1 0213083.1

专利申请日：2009年11月10日

专利权人：南京工业大学；中铁大桥勘测设计院有限公司

授权公告日：2011年02月02日

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2011年02月02日

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Project Example Ⅰ: Fuzhou Wulong River Bridge


- ➢The size of the structure is 11m (length) ×2m (width) × 1m (thickness);
- ➢Large structure manufactured by Vacuum Infusion Molding Process (VIMP);
- ➢ Bump tenon and mortise joints between segments.

Project Example Ⅰ: Fuzhou Wulong River Bridge

Project Example Ⅰ: Fuzhou Wulong River Bridge

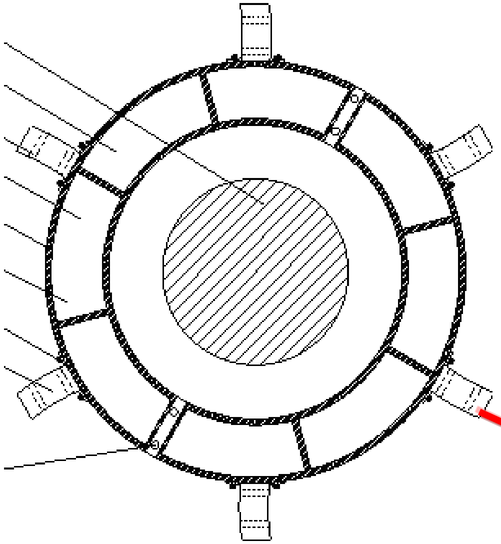
floating anti-collision system

Project Example Ⅱ: Zhangjiagang Wushan Arch Bridge

Project Example Ⅲ: Changzhou Hua Bo Hui Bridge

floating anti-collision system

Project Example Ⅳ: Changzhou Shijia Bridge



The anti-collision system can **rotate**

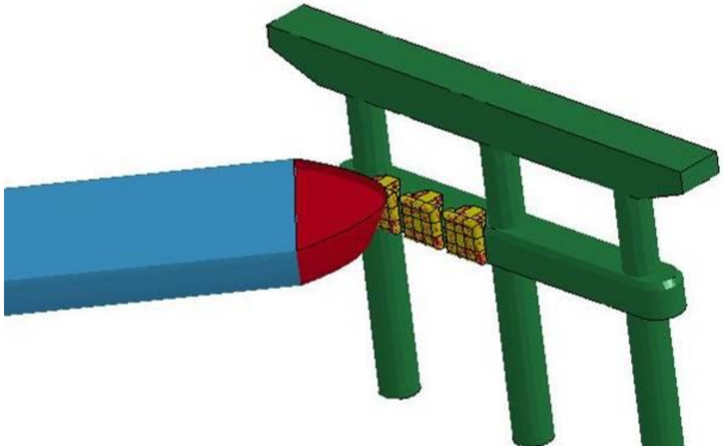
With flange

Project Example Ⅴ: Changzhou Xinmengge Bridge

The original bridge: navigation capacity 100t.

The bridge with anti-collision system: navigation capacity 300t.

- Changzhou Xinmengge bridge fixed type anti-collision system is composed of several 7 shape composite anti-collision fender.
- It is convenient to install and replace.

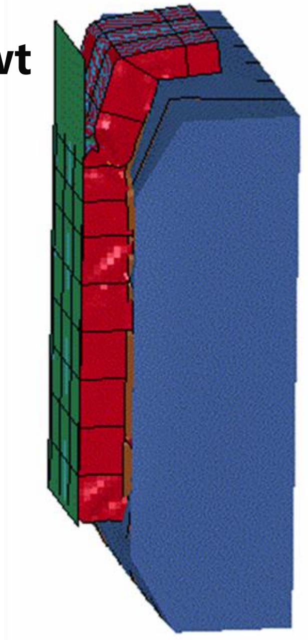


Project Example Ⅵ: Hongkong-Zhuhai-Macao Bridge

- fixed anti-collision fender system

Flat compress stiffness: 1.12MN/mm

5000t bowt



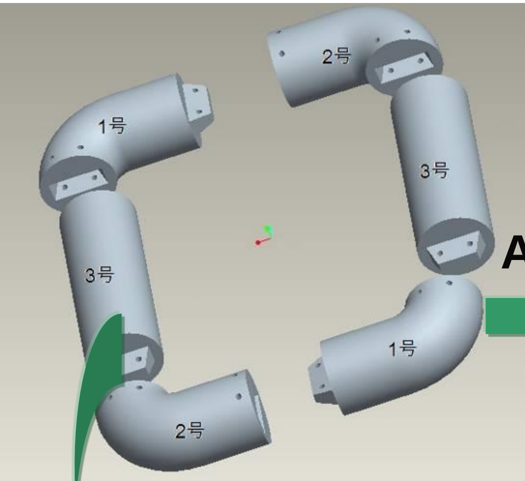
Project Example Ⅶ: Langqi Minjiang Bridge

- **Fixed and floating composite anti-collision system**

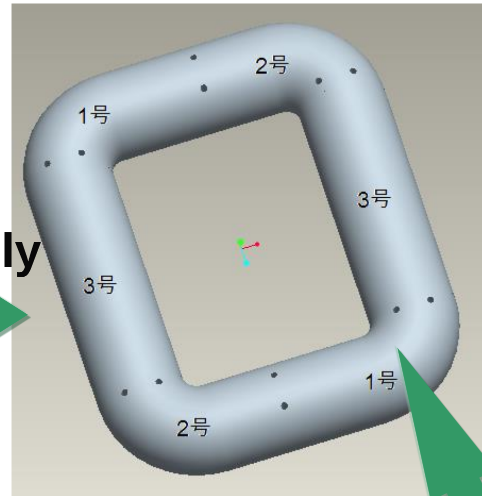
Project Example Ⅶ: Langqi Minjiang Bridge

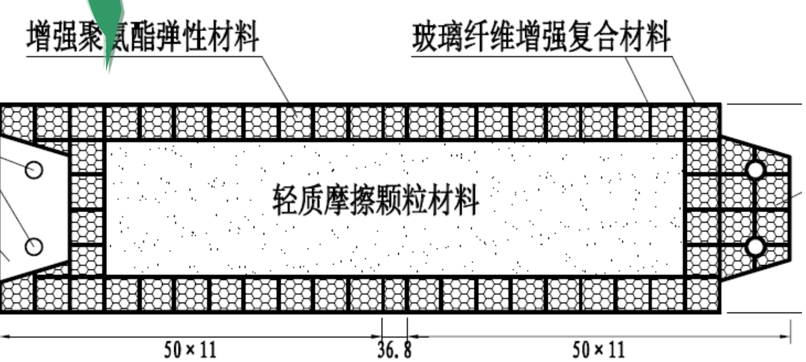
Project Example Ⅶ: Langqi Minjiang Bridge

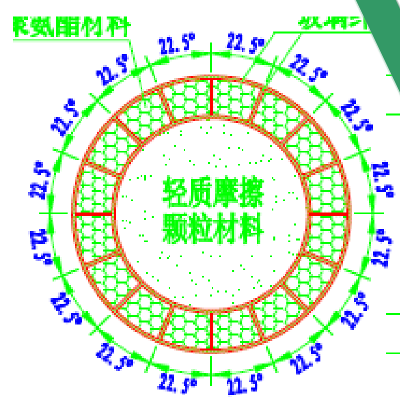
Project Example Ⅷ: The North Bridge of Runyang Bridge on Yangtze River

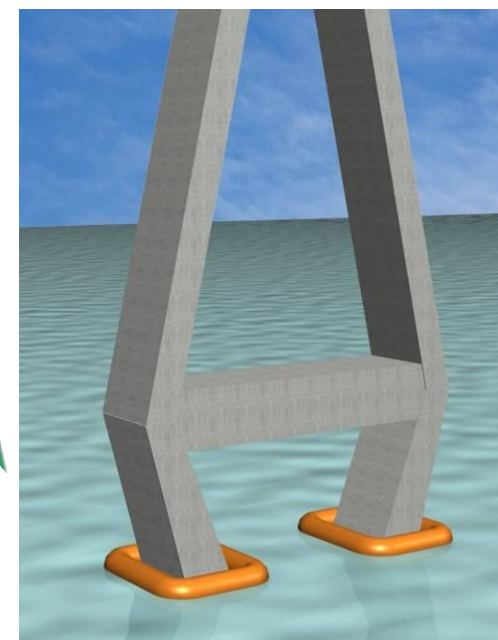


Assembly









Honeycomb web reinforced fome core FRP structure

Project Example Ⅷ: The North Bridge of Runyang Bridge on Yangtze River

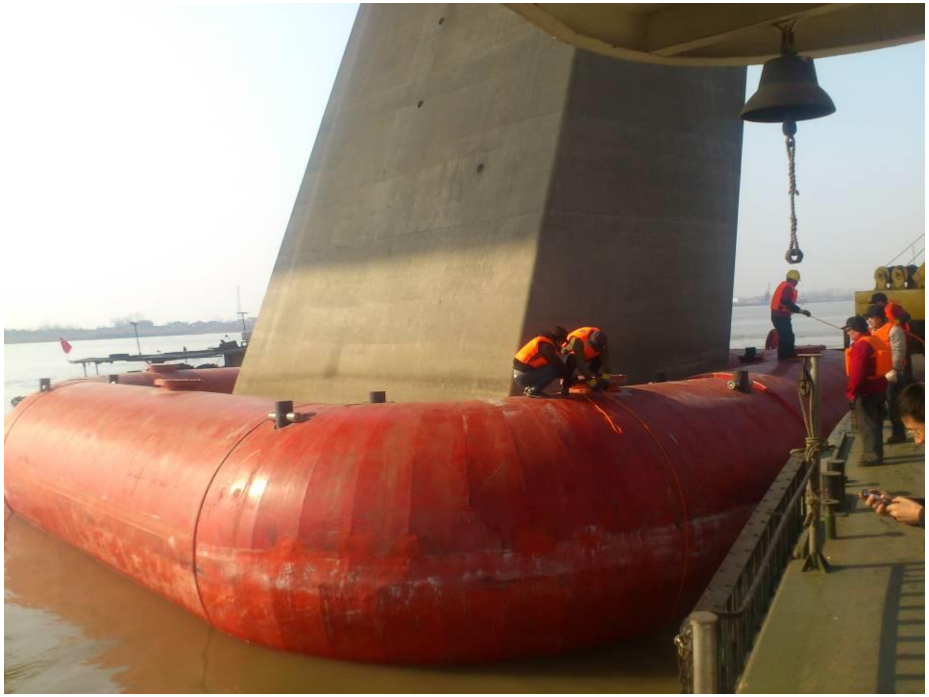




The diameter of this cylinder-shaped FRP composite structure unit is 3.5 m, and the length is 12 m.

Project Example Ⅷ: The North Bridge of Runyang Bridge on Yangtze River

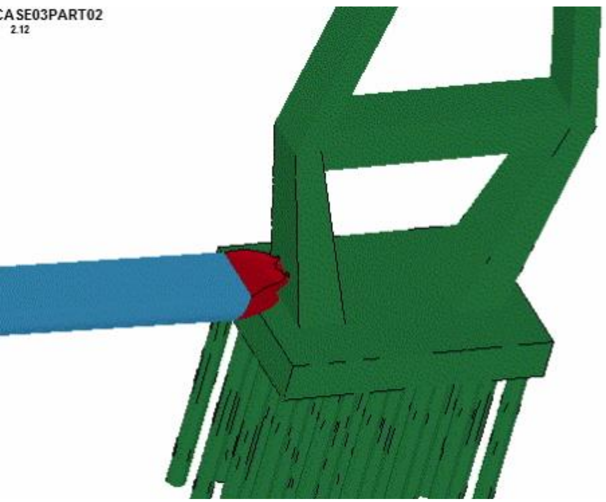
Project Example Ⅷ: The North Bridge of Runyang Bridge on Yangtze River

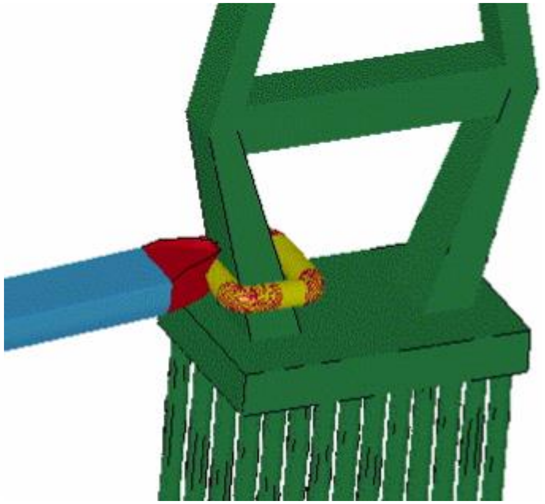


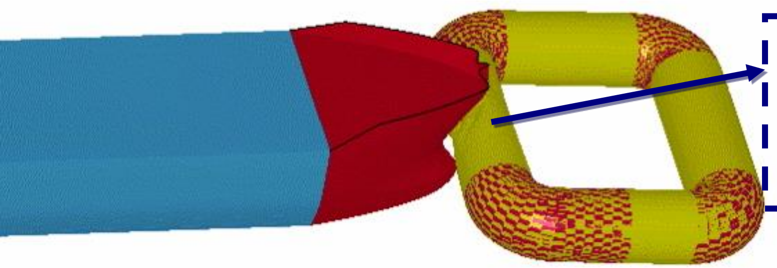
Advantages:

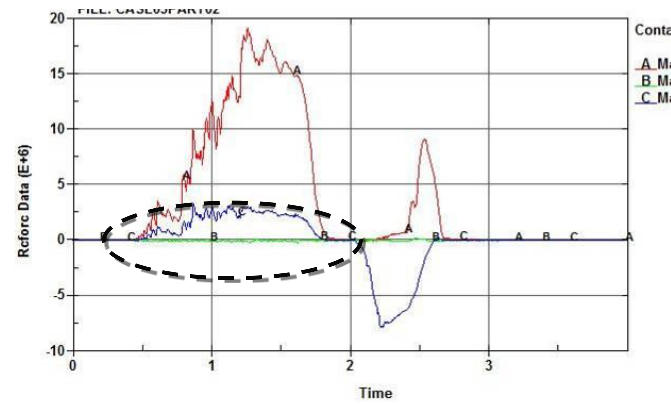
- floating
- Excellent corrosion resistance
- Excellent elasticity

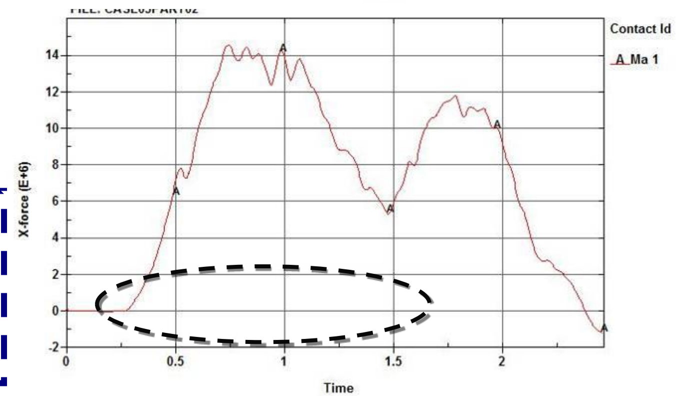
FEA Modelling: The North Bridge of Runyang Bridge on Yangtze River











Reduce damage of bow

Contact time: 1.0s ⟶ 1.3s

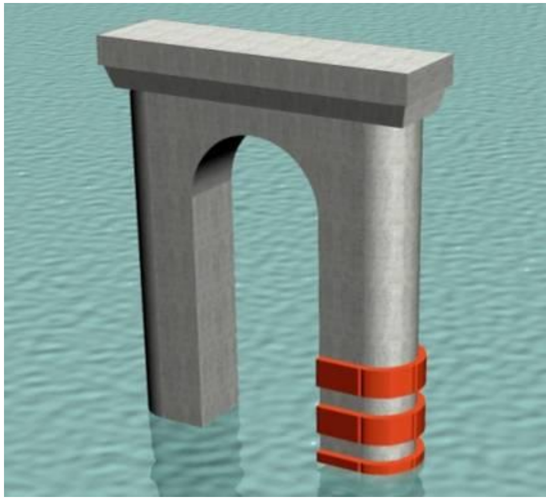
- 3000DWT vessel； velocity:3m/s
- When we install the anti-collision system, the maximum impact force can be reduced 40% from 19.95MN to 13.16MN

Project Example Ⅸ: Guangzhou-Shenzhen High-Speed Way Along the Sea Bridge (Shenzhen Section)

Winding cylinder-shaped FRP composite structure

Project Example Ⅸ: Guangzhou-Shenzhen High-Speed Way Along the Sea Bridge (Shenzhen Section)

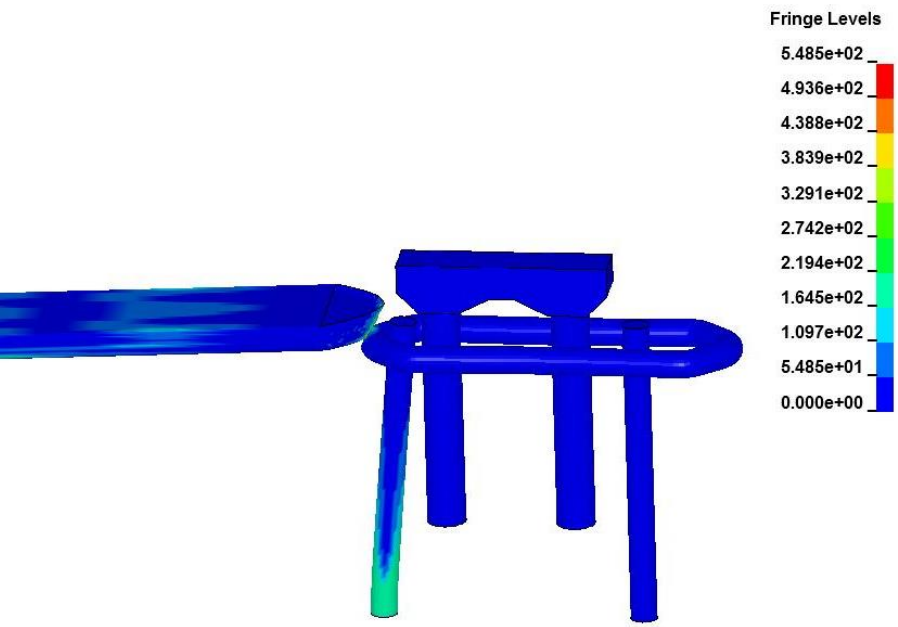
Project Example Ⅹ: The Huanggang Bridge(vehicle and train) on Yangtze River

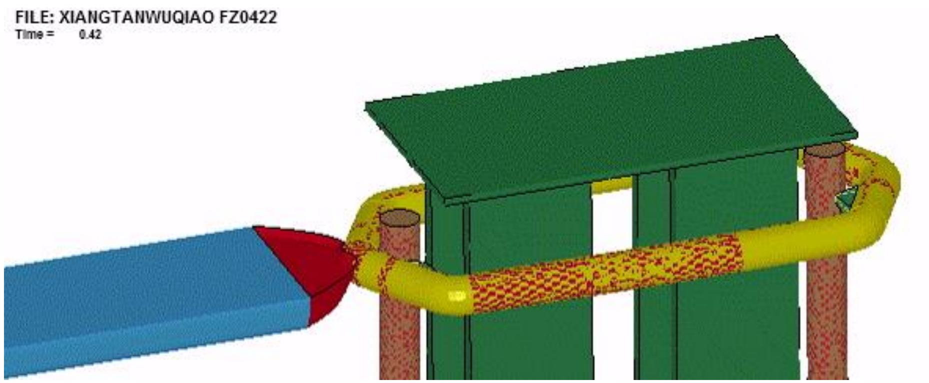


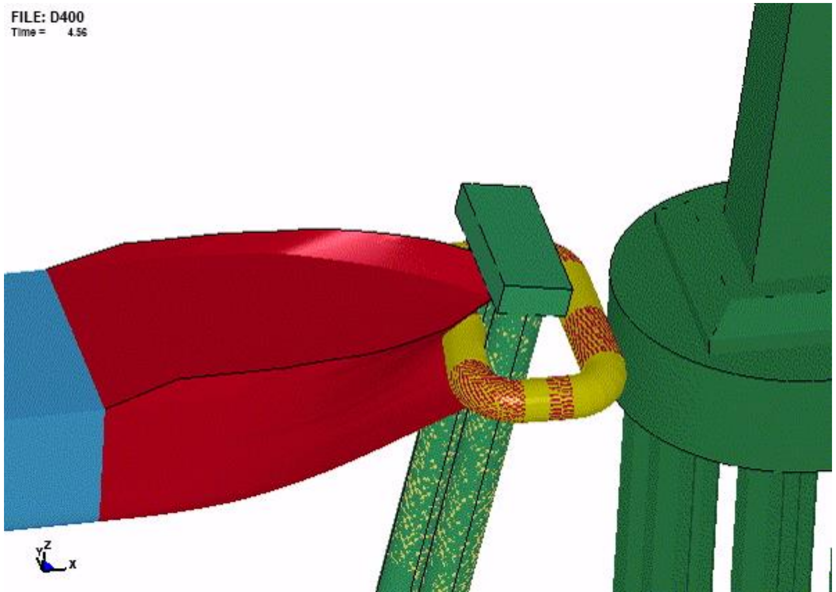
- fixed anti-collision composite fender system on the pier

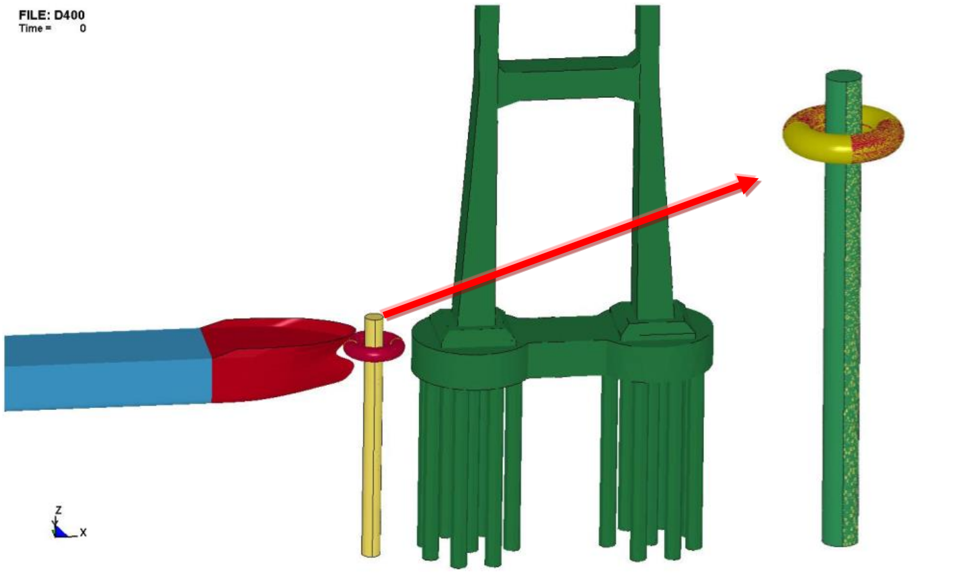
Project Example Ⅹ: The Huanggang Bridge(vehicle and train) on Yangtze River

Other Project: steel tube+composite loop

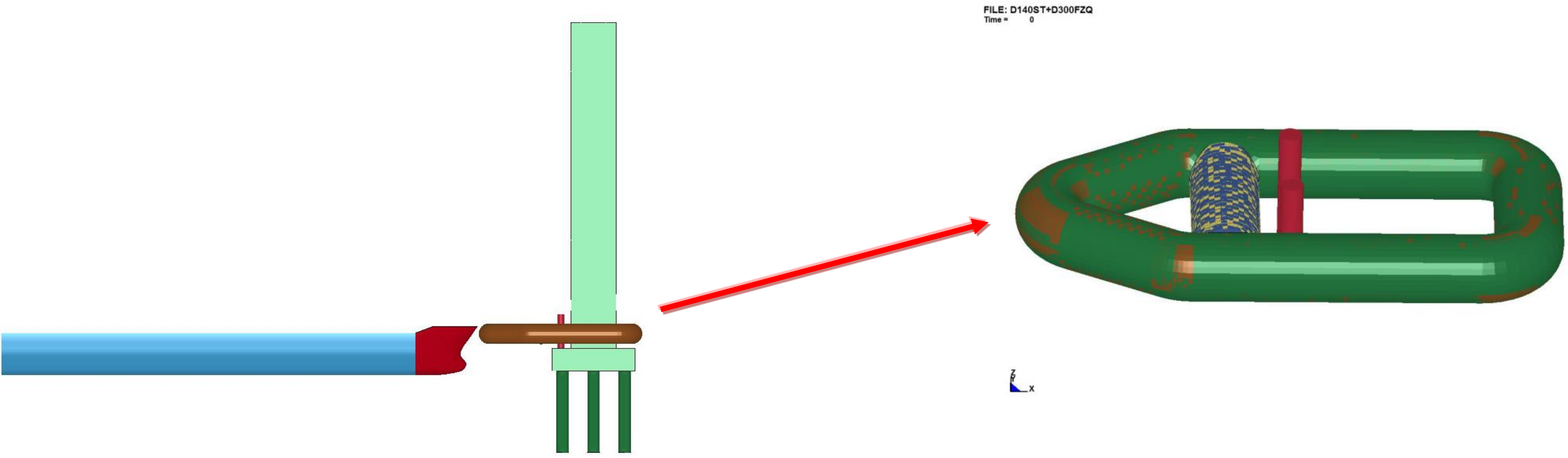


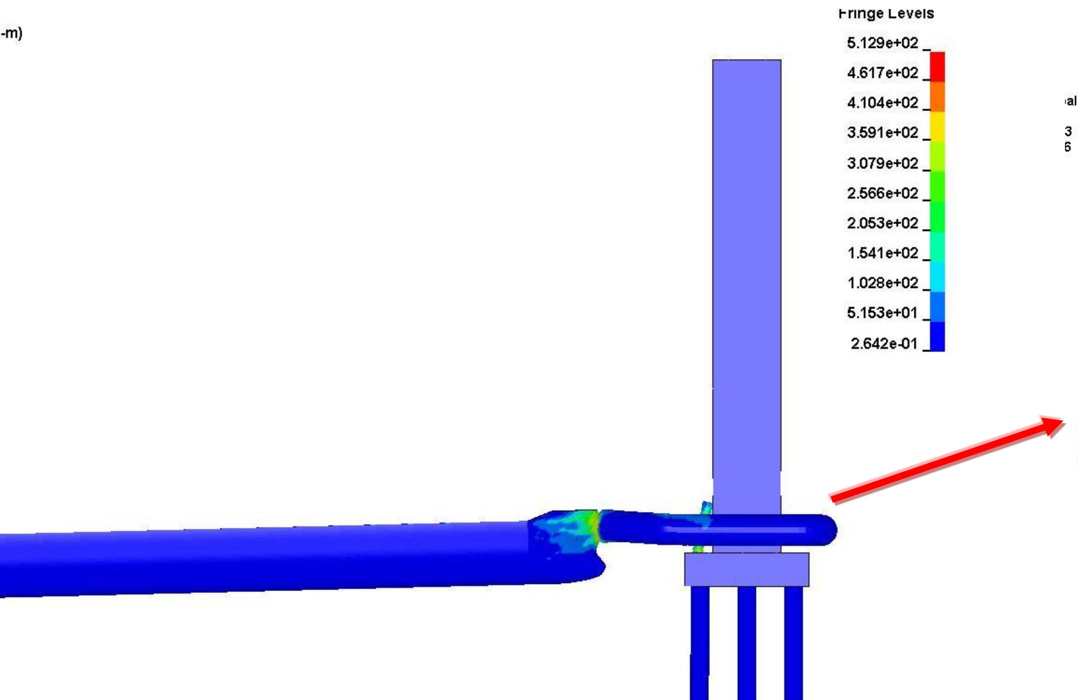


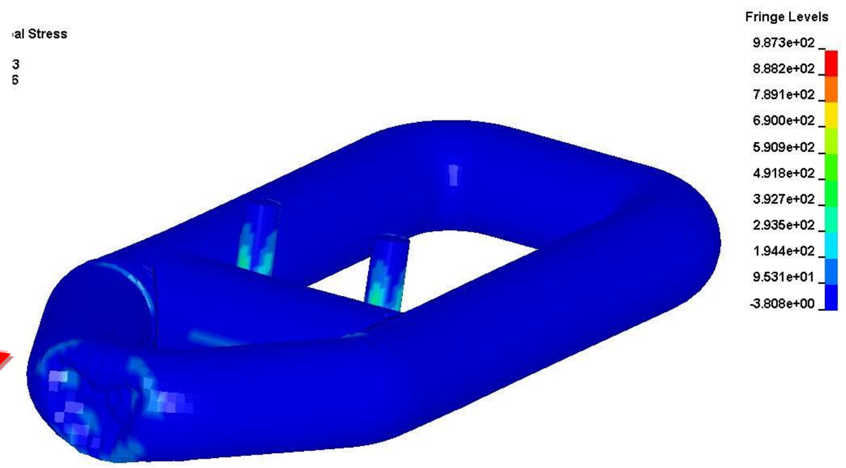




Other Project: steel tube+composite loop







Sutong Bridge

Ⅱ. Our team:Advanced Engineering Composites Research Center in NJTECH

Advanced Engineering Composites Research Center

State Key Laboratory of Materials-Oriented Chemical Engineering **(MCE)**
Jiangsu Province Key Laboratory of Civil Engineering and Disaster Mitigation

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Advanced Engineering Composites Research Center
4000 m^2 area, completed related equipments

The center is invited to become the overseas research center of the Center for Integration of Composites into Infrastructure (CICI) of West Virginia University, USA.

Center for Integration of Composites into Infrastructure

Our Team

➢ Director of the research center

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Chief professor of civil engineering disciplines of NJUT
Vice president of NJUT
Director of Jiangsu Province Key Laboratory of Civil Engineering and Disaster Mitigation
Research Interests: **composite structures & Structural vibration control**

➢ Members of the research center

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Thank you for your attention !

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