Stainless Steel in Structures:

Fifth International Experts Seminar

SOUTHEAST UNIVERSITY

Chinese Design Specification for Stainless Steel Structures, Researches and Applications

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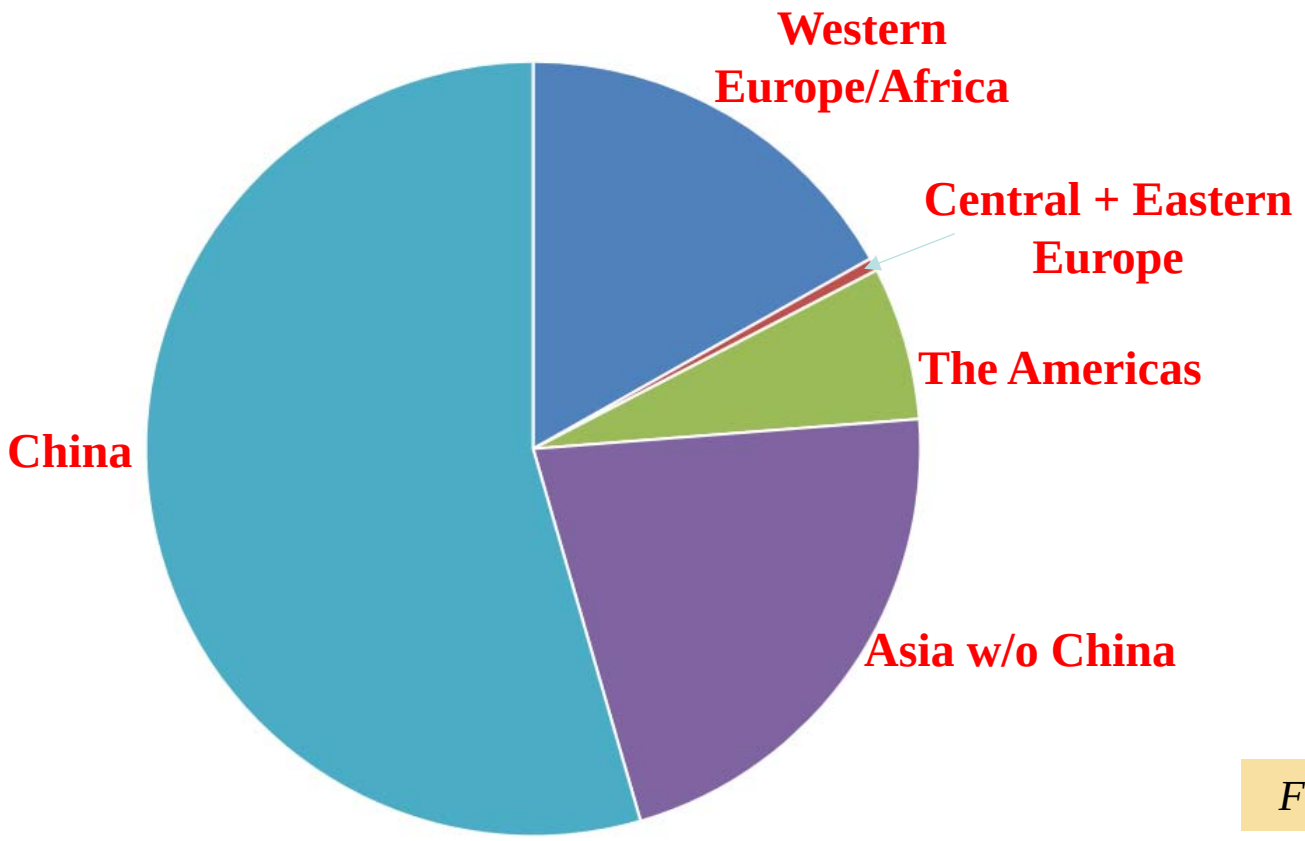
19th Sep 2017, London, UK

OUTLINE

- Introduction
- Content of Chinese Design Specification
- Undergoing Researches
- Applications
- Summary

1. Introduction

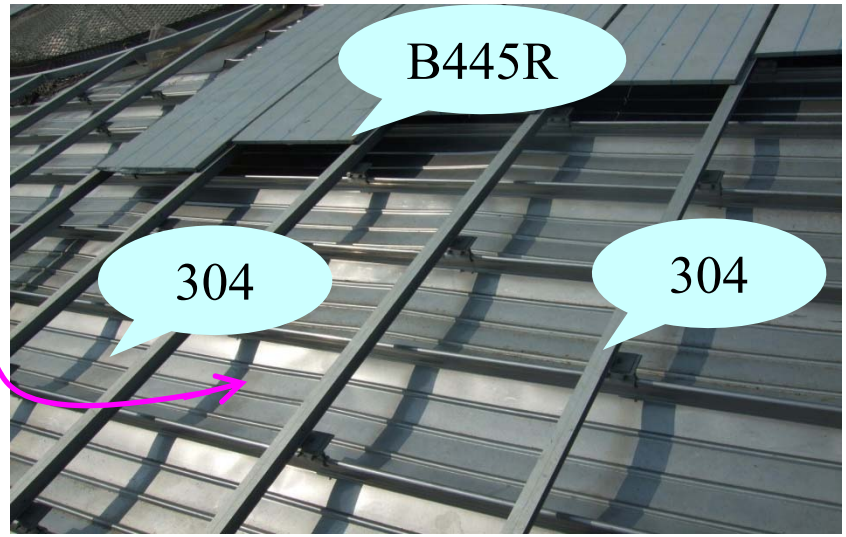
- Stainless steel structures in China
  - More than half of stainless steel in the world was produced in China. About 25 million Tons in 2016.



From ISSF 2016

1. Introduction

- Stainless steel structures in China
  - Widely used as Roof boarding, Coating, Interior decoration, and Glass curtain wall.



- ✓ B445R-external decorative panel;
- ✓ 304-waterproofing panel and keel

Stadium of Asian Games-Guangzhou, 2010

1. Introduction

- Stainless steel structures in China
  - Before the design specification was issued, stainless steel structures have been used in some projects.

Human and Nature Museum
Kunming,1999

Kunlun Station of China
Antarctic Research Station, 2009

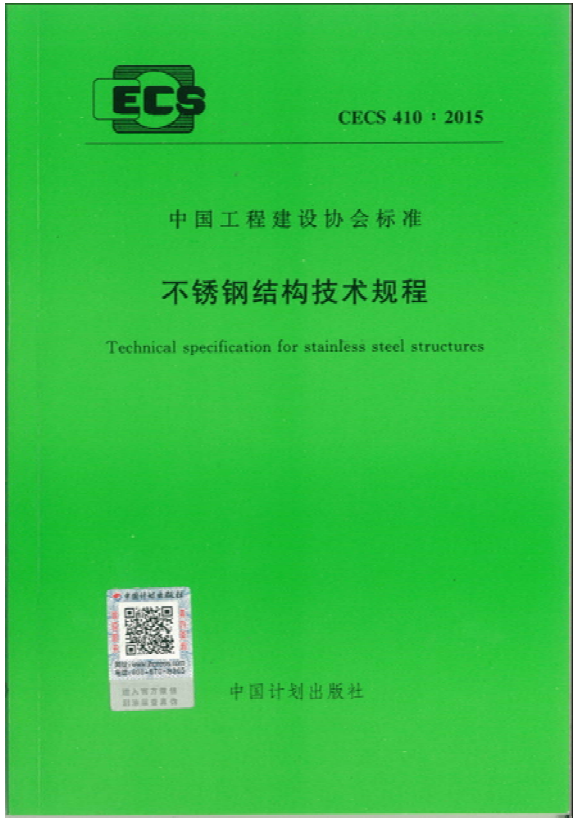
1. Introduction

- Stainless steel structures in China
  - Chinese design specification was issued on Dec. 2015

    Technical specification for stainless steel structures
    CECS 410
- Basic information
  - Including eight chapters
  - Suitable for welded cross section and cold formed cross section
  - Based on the frame of ***Technical Code of Cold-Formed Thin-Wall Steel Structures*** *GB 50018*
  - Not suitable for structures subjected to dynamical loading with a risk of fatigue

2. Content of Chinese specification

- Content:
  - Chapter 1: General provisions
  - Chapter 2:Terms and symbols
  - Chapter 3:Materials
  - Chapter 4:Basic requirements of design
  - Chapter 5:Design of members
  - Chapter 6:Design of connections
  - Chapter 7:Protection
  - Chapter 8: Fabrication and assembly



2.1 Materials

- Materials:
  - Six grades are included: four Austenitic and two Duplex.
  - The material properties are provided in annealed condition.

Type	Grade in Number	Grade In Chinese code GB/T 20878-2007	Nominal Value(N/mm²)		Design value (N/mm²)			EN 10088-2
			$f_{0.2}$	f_u	Tension f	Shear f_v	Local compression f_{ce}	
Austenitic	S30408	06Cr19Ni10	205	515	175	100	450	1.4301
	S30403	022Cr19Ni10	170	485	145	85	420	1.4307
	S31608	06Cr17Ni12Mo2	205	515	175	100	450	1.4401
	S31603	022Cr17Ni12Mo2	170	485	145	85	420	1.4404
Duplex	S22053	022Cr23Ni5Mo3N	450	620	385	220	540	1.4462
	S22253	022Cr22Ni5Mo3N	450	620	385	220	540	

✓ Partial resistance factor of material is adopt as 1.165.

2.1 Materials

Materials: welds and bolts

Grade	Electrode	Butt weld				Fillet weld
		Strength in compression f_c^w	Strength in tension f_t^w		Strength in shear f_v^w	Strength f_f^w
			Class 1 and 2	Class 3		
S30408	E308	175	175	150	100	175
S30403	E308L	145	145	125	85	145
S31608	E316	175	175	150	100	175
S31603	E316L	145	145	125	85	145
S22053 S22253	E2209	385	385	325	220	260

Welds

- ✓ Weld between carbon steel and stainless steel is forbidden.
- ✓ Strength of fillet welds is equal to the material yield strength.

Grade	Bolts identity		Diameter (mm)	Ultimate Strength f_u^b (N/mm²)	Design strength (N/mm²)				
	Group	Grade			In tension f_t^b	In shear f_v^b	In compression f_c^b		
							S30408 S31608	S30403 S31603	S22053 S22253
S30408 S30403 S31608 S31603	A2, A3, A4, A5	50	M≤39	500	190	155	410	400	—
		70	M≤39	700	295	245	410	400	—
		80	M≤24	800	335	280	410	400	—

Bolts

- ✓ No bolt is available for duplex stainless steel.

2.2 Design of cross section

- For stocky cross section:
  - No plasticity and strain hardening is allowed to be used in design.
  - Cold forming effect is not considered in the current version.
- For slender cross section:
  - Effective width method is used.

$$\frac{b_e}{t}=\begin{cases}\left(\alpha_1-\alpha_2\sqrt{\bar{\lambda}_p}\right)\dfrac{b_c}{t}\le\dfrac{b_c}{t} & \bar{\lambda}_p\le 1.0\\ \left(\dfrac{\bar{\lambda}_p}{\alpha_3\bar{\lambda}_p-\alpha_4}\right)\dfrac{b_c}{t} & 1.0<\bar{\lambda}_p\le 1.5\\ \left(\dfrac{\alpha_5\bar{\lambda}_p+\alpha_6}{\bar{\lambda}_p}\right)\dfrac{b_c}{t} & \bar{\lambda}_p>1.5\end{cases}$$

- ✓ **Two curves** are given for plates in different fabrication methods.
- ✓ Only for local buckling. **Distortional buckling is not included currently**.

	α_1	α_2	α_3	α_4	α_5	α_6
Cold-formed	2.41	-1.63	3.15	-1.86	0.092	0.65
Welded	1.84	-1.14	3.15	-1.72	0.086	0.62

2.3 Design of columns

- Based on test data and finite element results, **Six column curves** are given in the form of Perry formula.

$$\sigma = \frac{N}{\varphi A_e} \le f$$

$$\varphi = \frac{1}{\phi_c + \sqrt{\phi_c^2 - \bar{\lambda}^2}} \le 1.0$$

$$\phi_c = 0.5\left[1 + \alpha_c\left(\bar{\lambda} - \bar{\lambda}_c\right) + \bar{\lambda}^2\right]$$

Material	Cross section	α_c	λ_c
Austenitic Duplex	Cold-formed RHS, SHS, Lipped-C (un-annealed condition)	0.60	0.56
	Cold formed CHS, OHS	0.36	0.00
Austenitic	Welded box Welded H major axis	0.66	0.24
	Welded H minor axis	0.89	0.26
Duplex	Welded box Welded H major axis	0.51	0.37
	Welded H major axis	0.69	0.37
Austenitic Duplex	Others	0.89	0.26

✓ Column curves dependent on cross sections, material grades and fabrication methods.

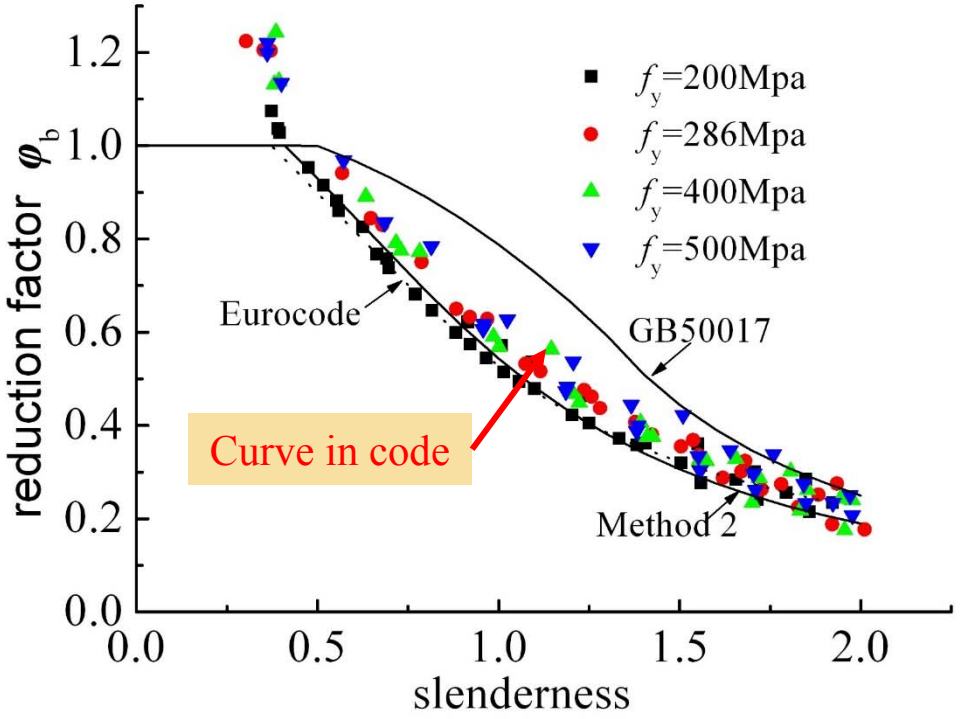
2.4 Design of beams

- Based on test data and finite element results, lateral-tortional buckling curve is given in the form of Perry formula.

$$\varphi_b = \frac{1}{\phi_b + \sqrt{\phi_b^2 - \bar{\lambda}_\omega^2}} \le 1.0$$

$$\phi_b = 0.5\left[1 + 0.65\left(\bar{\lambda}_\omega - 0.41\right) + \bar{\lambda}_\omega^2\right]$$

$$\bar{\lambda}_\omega = \sqrt{\frac{W_x f_{0.2}}{M_{cr}}}$$

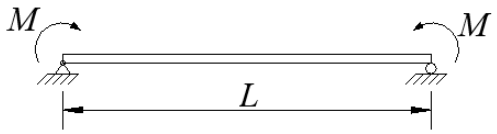
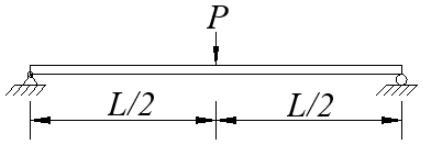
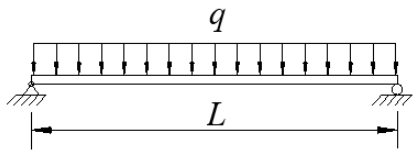


2.4 Design of beams

Deflection: Approximate curvature method

Curvature $$\chi = \frac{M}{E_0 I} + 0.004\left(\frac{M}{M_{0.2}}\right)^n$$

✓ Deflection can be determined by a direct integration procedure of the curvatures based on the principle of virtual work.

Load Cases	Deflection at the middle length
	$\frac{ML^2}{8E_0I_e} + \frac{0.004}{h}\left(\frac{M}{M_{ey}}\right)^n \frac{L^2}{8}$
	$\frac{PL^3}{48E_0I_e} + \frac{0.004}{h}\left(\frac{PL}{4M_{ey}}\right)^n \frac{L^2}{4(n+2)}$
	$\frac{5qL^4}{384E_0I_e} + \frac{0.004}{h}\left(\frac{qL^2}{2M_{ey}}\right)^n \frac{L^2}{10}\cdot e^{-1.45n}$

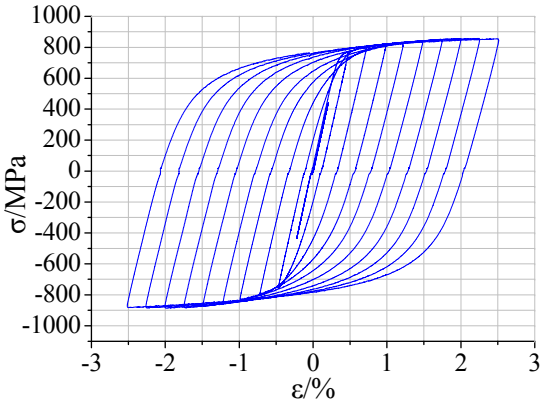
Max deflection for typical cases

3. Undergoing researches

- Seismic performance
- Behaviors of new type of structural stainless steel
- Fire resistance
- Joint behaviors
- Slip-resistance bolt connections
- Compiling related codes/standards

3.1 seismic performance

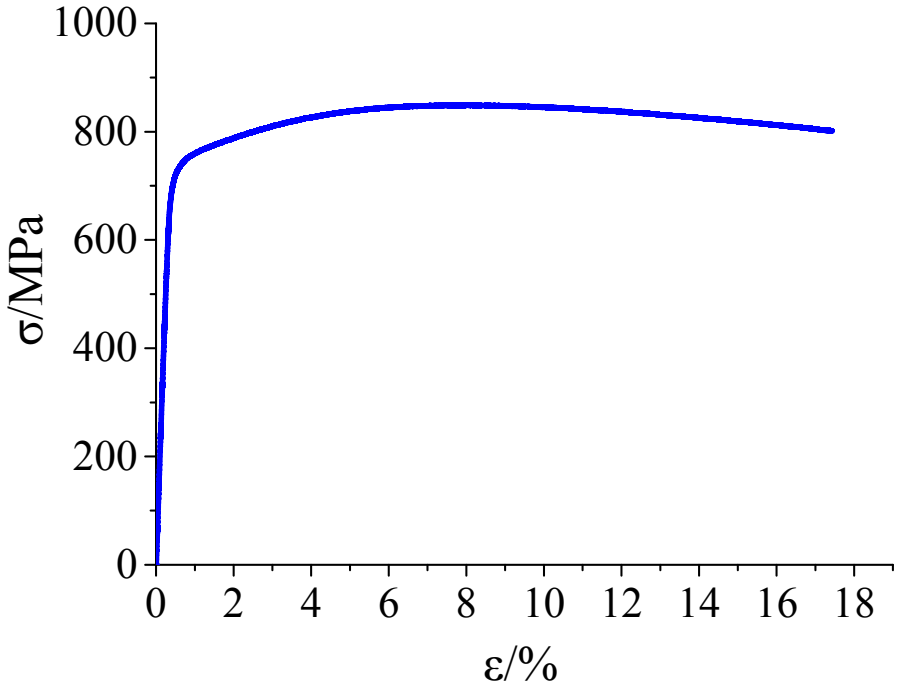
- Current condition:
  - More than 90% area in China subjected to earthquake.
  - design rules for carbon steel structures is directly used for stainless steel structures in CECS 410.
- Researches:
  - Material properties under low cycle loading—SEU and BJUT
  - Members behavior under cyclic loading—TJU and BJUT
  - Joints behavior under cyclic loading—THU



3.2 Behaviors of new structural stainless steel

- New high strength **Sorbite stainless steel** is developed by Nickel Resources International Holdings Company Limited.
  - Higher in strength and lower in price

Material tensile test in Southeast University

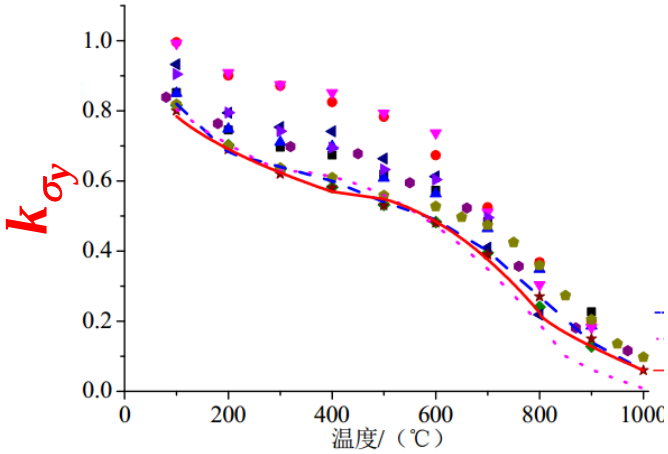


- ✓ Yield stress: >600MPa
- ✓ Elongation: 18%~23%
- ✓ Corrosion resistance: 70% of S30408
- ✓ Price: 9000 RMB /Ton, 70% of S30408

***Technical specification for high strength sorbite stainless steel structures* is under composing.**

3.3 fire resistance

- Current condition:
  - In CECS 410, no detail rules is available on the design of fire resistance. Most of the rules are from those for carbon steel structures.
- Researches:
  - Material properties at elevated temperatures—**SEU**
  - Members behavior in fire—**SEU**



Reduction factor of yield stress

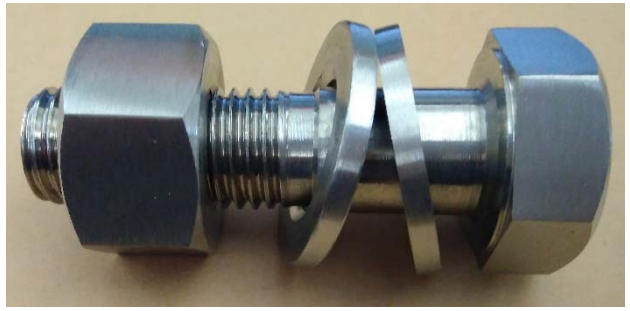
Members behaviors

3.4 Joint behaviors

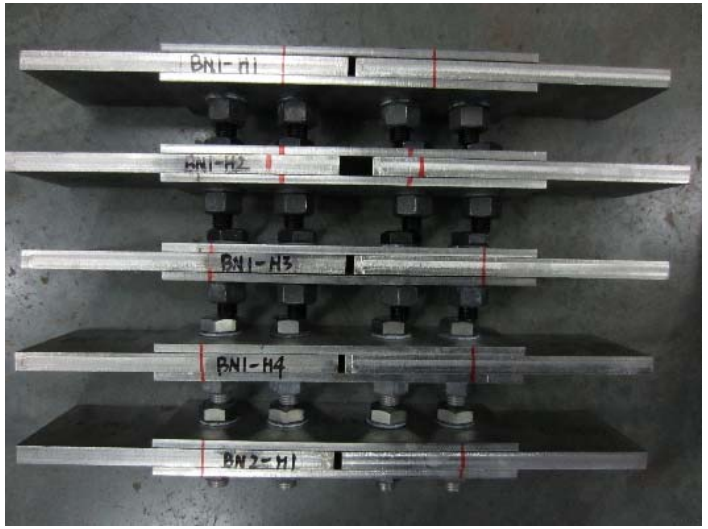
- Current condition:
  - Joints is the basic component in structures.
  - In CECS 410, no rule is for tubular joints and welded joints.
- Researches:
  - Behavior of tubular T,Y, K-joints—**SEU**
  - Behavior of welded Joints—**THU**

3.5 Slip-resistance bolt connections

- Current condition:
  - In CECS 410, high strength bolts are allowed to be used in structures. However, no stainless steel bolt (only coated high strength steel bolts) is available.
- Researches:
  - High strength stainless steel bolts
  - Surface treatment method



- ✓ Yield stress: 950 MPa
- ✓ Elongation: 10.5 %
- ✓ Corrosion resistance: similar to S30408



- ✓ Surface treatment: Polishing and Powder spraying
- ✓ Mean slip coefficient: 0.38

3.6 Composing related codes/standards

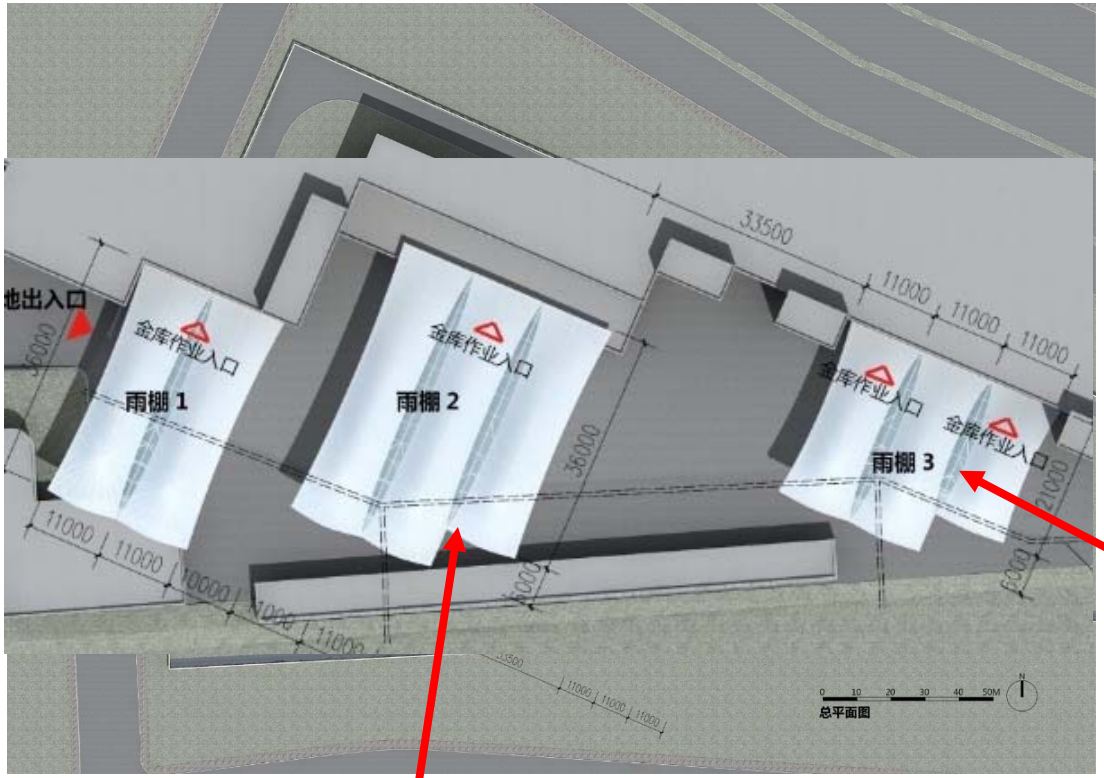
- Several codes and standards related to stainless steel structures are under compiling and drafting.

  - Technical code for steel structures----Chapter 10
  - Seismic design standard for industry structures----Index C
  - Technical specification for high strength sorbite stainless steel structures
  - Profiled stainless steel sheet for buildings
  - Welded stainless steel tubes for buildings

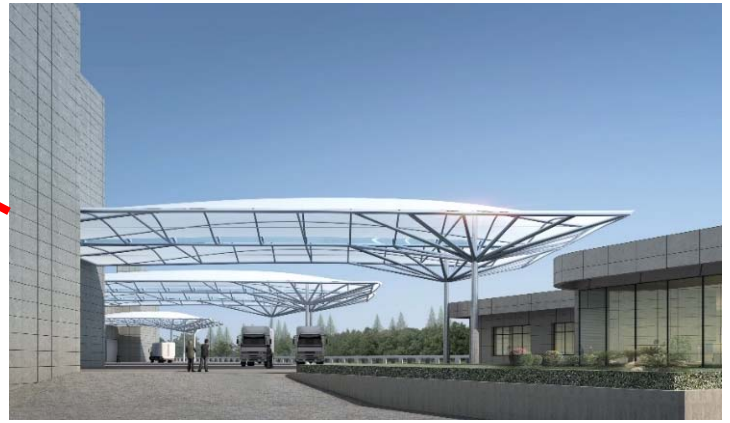
4.Two Applications

- Tubular spatial structure in Nanjing

Site-plan



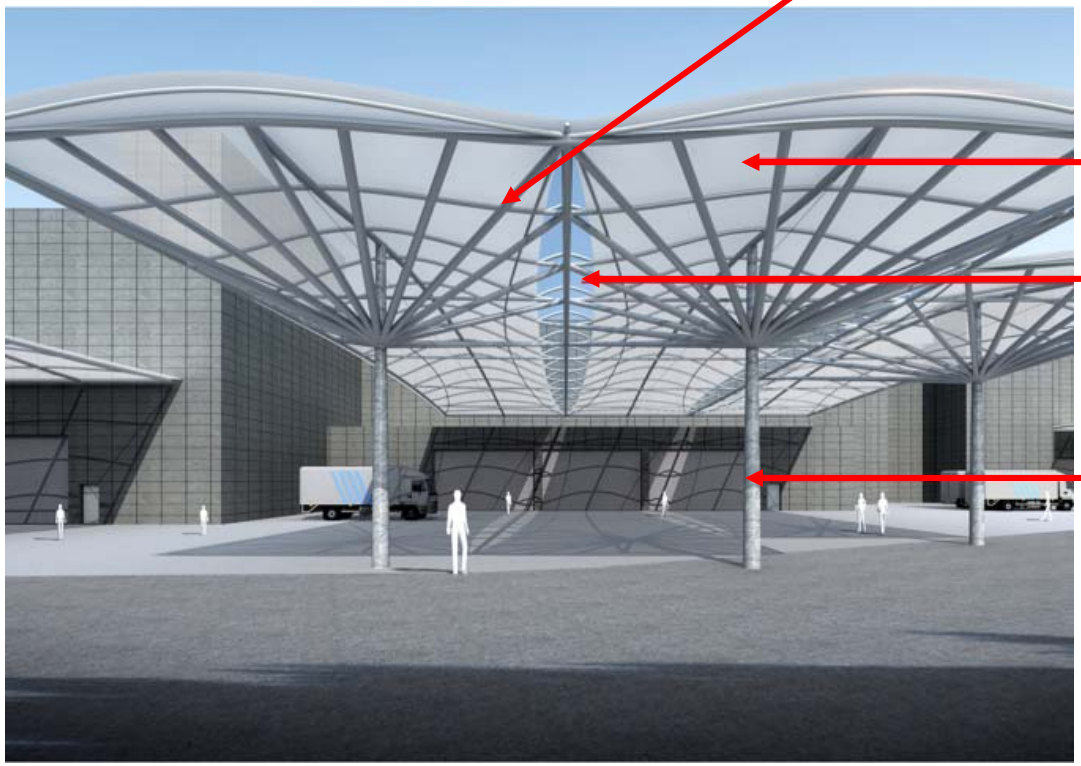
- ✓ Material: S30408
- ✓ Cross section: CHS
- ✓ Size: 44.3m×33m



Length × Span=44.3×33m

4.Two Applications

- Tubular space structure in Nanjing



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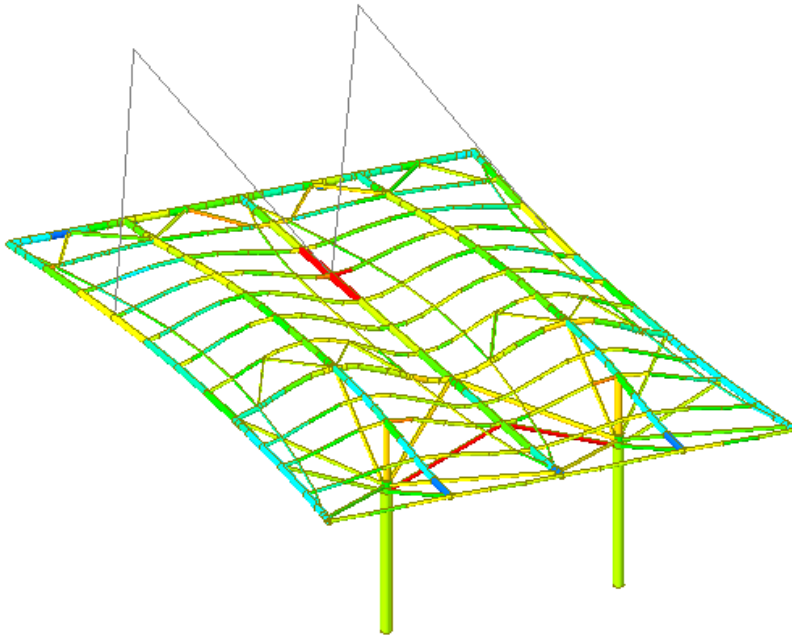
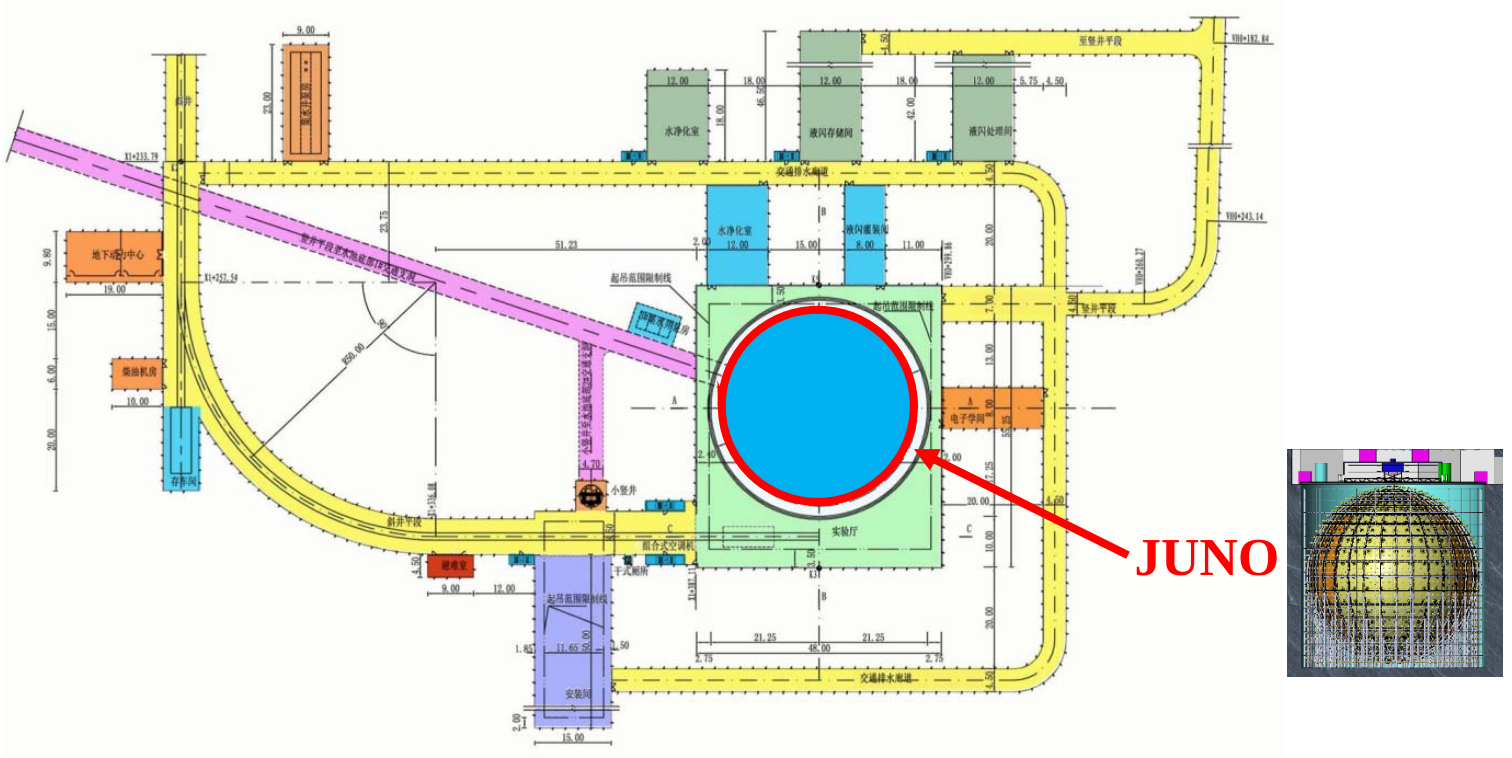


Analysis model

Under construction

4.Two Applications

- JUNO:
  - a complicate huge test machine for physical scientists
  - 700 meters depth underground

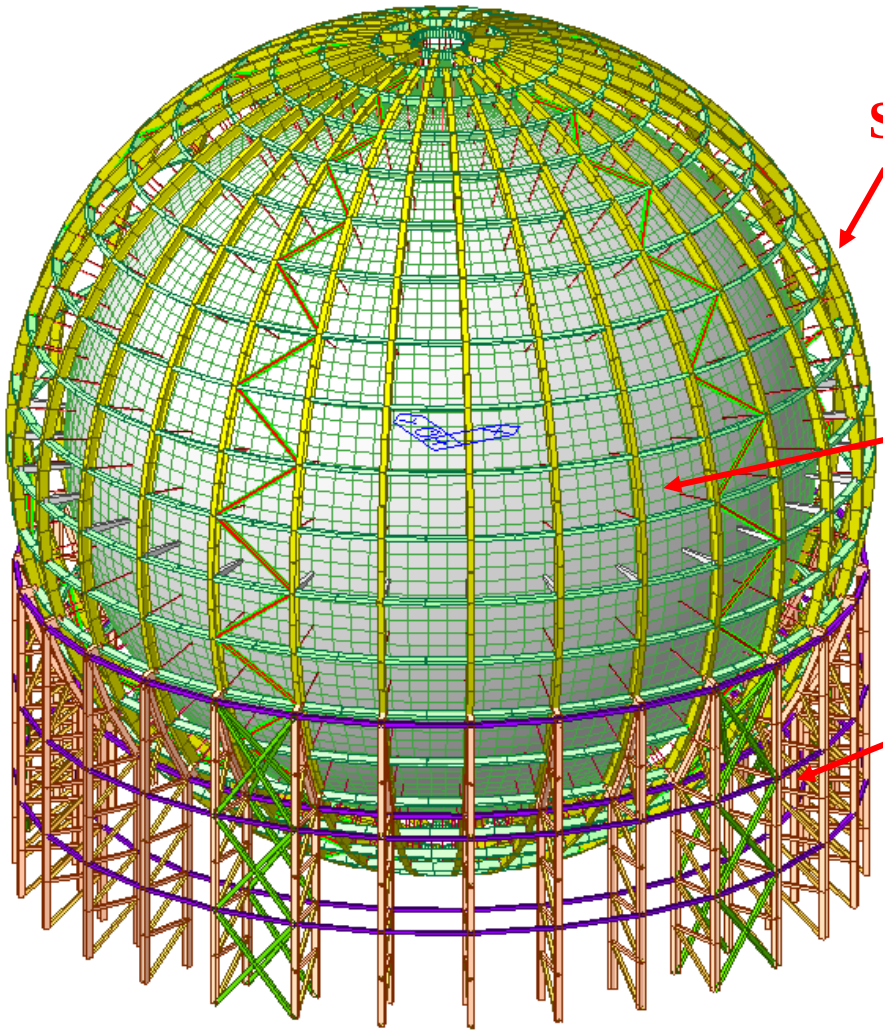


Site plan (-700m)

4.Two Applications

JUNO:

- ✓ Material: S30408
- ✓ Diameter: 40.1m
- ✓ Welded H section
- ✓ Prefabricated structure
- ✓ No weld on site



Under construction

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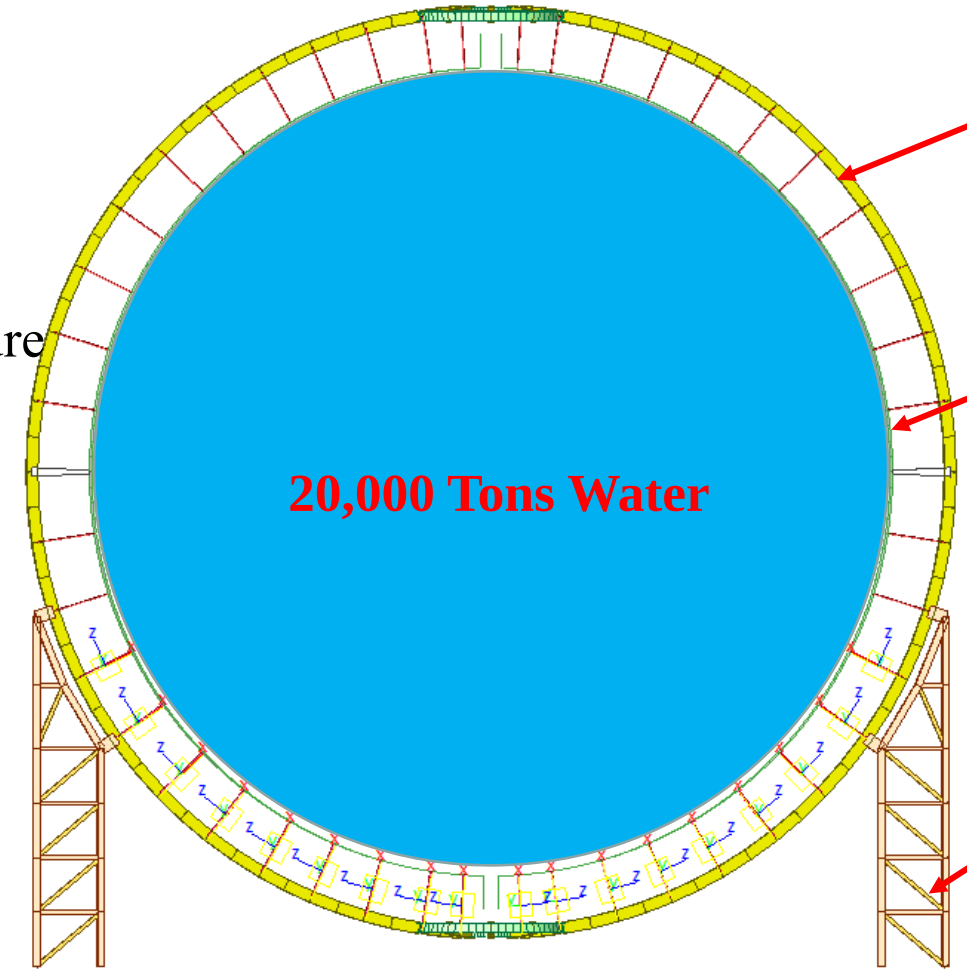

Under construction

5. Summary

- Chinese design specification has been issued. Several design codes related to stainless steel structures are under compiling. These design specification/codes play an important role in promoting the use of stainless steel structures in China.
- Current version focuses on basic design rules for members and connections. Researches on properties of new material, seismic performance, etc. are undergoing.

5. Summary

- "The Land and Maritime Silk Road Initiative" calls more design and construction specifications on stainless steel structures which match international level.

Thank you!