



# FINAL DRAFT International Standard

## ISO/FDIS 16521

### Design of concrete-filled steel tubular (CFST) hybrid structures

ISO/TC 71

Secretariat: **JISC**

Voting begins on:  
**2024-07-09**

Voting terminates on:  
**2024-09-03**

iTeh Standards  
(<https://standards.itih.ai>)  
Document Preview

[ISO/FDIS 16521](https://standards.itih.ai/catalog/standards/iso/32348305-cb27-4689-ac42-e8dadf13165b/iso-fdis-16521)

<https://standards.itih.ai/catalog/standards/iso/32348305-cb27-4689-ac42-e8dadf13165b/iso-fdis-16521>

RECIPIENTS OF THIS DRAFT ARE INVITED TO SUBMIT, WITH THEIR COMMENTS, NOTIFICATION OF ANY RELEVANT PATENT RIGHTS OF WHICH THEY ARE AWARE AND TO PROVIDE SUPPORTING DOCUMENTATION.

IN ADDITION TO THEIR EVALUATION AS BEING ACCEPTABLE FOR INDUSTRIAL, TECHNOLOGICAL, COMMERCIAL AND USER PURPOSES, DRAFT INTERNATIONAL STANDARDS MAY ON OCCASION HAVE TO BE CONSIDERED IN THE LIGHT OF THEIR POTENTIAL TO BECOME STANDARDS TO WHICH REFERENCE MAY BE MADE IN NATIONAL REGULATIONS.

iTeh Standards  
(<https://standards.iteh.ai>)  
Document Preview

[ISO/FDIS 16521](https://standards.iteh.ai/catalog/standards/iso/32348305-cb27-4c89-ac42-e8dadf13165b/iso-fdis-16521)

<https://standards.iteh.ai/catalog/standards/iso/32348305-cb27-4c89-ac42-e8dadf13165b/iso-fdis-16521>



**COPYRIGHT PROTECTED DOCUMENT**

© ISO 2024

All rights reserved. Unless otherwise specified, or required in the context of its implementation, no part of this publication may be reproduced or utilized otherwise in any form or by any means, electronic or mechanical, including photocopying, or posting on the internet or an intranet, without prior written permission. Permission can be requested from either ISO at the address below or ISO's member body in the country of the requester.

ISO copyright office  
CP 401 • Ch. de Blandonnet 8  
CH-1214 Vernier, Geneva  
Phone: +41 22 749 01 11  
Email: [copyright@iso.org](mailto:copyright@iso.org)  
Website: [www.iso.org](http://www.iso.org)

Published in Switzerland

# Contents

	Page
<b>Foreword</b> .....	<b>vii</b>
<b>Introduction</b> .....	<b>viii</b>
<b>1 Scope</b> .....	<b>1</b>
<b>2 Normative references</b> .....	<b>1</b>
<b>3 Terms and definitions</b> .....	<b>1</b>
<b>4 Symbols</b> .....	<b>5</b>
<b>5 Materials</b> .....	<b>7</b>
5.1 General.....	7
5.2 Concrete.....	8
5.2.1 Cement.....	8
5.2.2 Aggregates.....	8
5.2.3 Water.....	8
5.2.4 Admixtures.....	8
5.2.5 Additions.....	8
5.2.6 Concrete mixture specification.....	8
5.3 Steel tubes.....	8
5.4 Steel reinforcement.....	9
5.4.1 Deformed reinforcement.....	9
5.4.2 Plain reinforcement.....	9
5.5 Other materials.....	9
5.5.1 Welding consumables.....	9
5.5.2 Fasteners.....	9
5.5.3 Protective paint systems.....	9
5.6 Storage of materials.....	9
<b>6 Design and construction procedure</b> .....	<b>9</b>
<b>7 General guides</b> .....	<b>11</b>
7.1 Limitations.....	11
7.1.1 CFST members.....	11
7.1.2 Trussed concrete-filled steel tubular (CFST) hybrid structures.....	12
7.1.3 Concrete-encased concrete-filled steel tubular (CFST) hybrid structures.....	12
7.2 Limit states.....	13
7.3 Ultimate limit state design format.....	14
7.3.1 General.....	14
7.3.2 Factored load effects.....	14
7.3.3 Design resistances.....	14
7.4 Serviceability limit state design format.....	15
<b>8 Specific guides</b> .....	<b>15</b>
8.1 Design working life.....	15
8.2 Selections of materials, structural plans and detailing.....	15
8.3 Seismic design requirements.....	15
8.4 Selections of constructional methods and techniques.....	15
<b>9 Actions (loads)</b> .....	<b>16</b>
9.1 General.....	16
9.2 Dead loads.....	16
9.3 Live loads.....	16
9.4 Snow loads.....	16
9.5 Wind forces.....	16
9.6 Earthquake forces.....	16
9.7 Thermal forces.....	17
9.8 Load partial factors and load combinations.....	17
<b>10 Analysis</b> .....	<b>17</b>

10.1	General.....	17
10.1.1	Structural analysis purpose.....	17
10.1.2	Structural analysis methods.....	17
10.1.3	Structural analysis requirements.....	17
10.1.4	Loading cases.....	18
10.1.5	Construction stage analysis.....	18
10.2	Stress-strain relationships for materials.....	18
10.2.1	General.....	18
10.2.2	Concrete.....	19
10.2.3	Steel.....	26
10.3	Indices for the strength and stiffness of CFST hybrid structures.....	28
10.3.1	CFST cross-section.....	28
10.3.2	CFST hybrid structures.....	30
<b>11</b>	<b>Ultimate limit states of trussed concrete-filled steel tubular (CFST) hybrid structures.....</b>	<b>31</b>
11.1	General.....	31
11.2	Resistances to compression and bending.....	31
11.2.1	Axial compression.....	31
11.2.2	Bending.....	34
11.2.3	Combined compression and bending.....	35
11.2.4	Resistances of CFST chords.....	38
11.2.5	Resistances of webs.....	44
11.3	Resistance to shear.....	45
11.3.1	With horizontal webs.....	45
11.3.2	With diagonal webs.....	45
<b>12</b>	<b>Ultimate limit states of concrete-encased concrete-filled steel tubular (CFST) hybrid structures.....</b>	<b>45</b>
12.1	General.....	45
12.2	Resistances of single-chord structures.....	45
12.2.1	Axial compression.....	45
12.2.2	Combined compression and bending.....	46
12.2.3	Tension.....	49
12.3	Resistances of four-chord structures.....	50
12.3.1	Axial compression.....	50
12.3.2	Combined compression and bending.....	50
12.4	Resistances of six-chord structures.....	53
12.4.1	Axial compression.....	53
12.4.2	Combined compression and bending.....	54
12.5	Resistances of slender structures.....	57
12.5.1	Axial compression.....	57
12.5.2	Combined compression and bending.....	57
12.6	Resistance subjected to long-term loading.....	58
12.7	Resistance to shear.....	58
12.8	Resistance to combined axial force, bending and shear.....	59
<b>13</b>	<b>Serviceability limit states of concrete-filled steel tubular (CFST) hybrid structures.....</b>	<b>60</b>
13.1	Calculation of structural response.....	60
13.2	Serviceability limitations.....	60
<b>14</b>	<b>Protective design.....</b>	<b>60</b>
14.1	General.....	60
14.1.1	Corrosion resistance.....	60
14.1.2	Fire resistance.....	60
14.1.3	Impact resistance.....	61
14.2	Design of corrosion resistance.....	61
14.2.1	Anti-corrosion measures.....	61
14.2.2	Corrosion resistance calculation.....	61
14.3	Design of fire resistance.....	62
14.3.1	Load ratio during fire.....	62
14.3.2	Fireproof coating.....	62

## ISO/FDIS 16521:2024(en)

14.3.3	Fire resistance ratings.....	63
14.3.4	Detailing requirements.....	63
14.4	Design of impact resistance.....	64
14.4.1	Bending resistance under impact.....	64
14.4.2	Dynamic increase factor for circular CFST chords under impact.....	64
14.4.3	Deformation of circular CFST chords under impact.....	65
<b>15</b>	<b>Connections.....</b>	<b>65</b>
15.1	General.....	65
15.2	Joints of trussed concrete-filled steel tubular (CFST) hybrid structures.....	65
15.2.1	General requirements.....	65
15.2.2	Typical forms of joints.....	66
15.2.3	Welding requirements.....	67
15.2.4	Detailing requirements of webs.....	67
15.2.5	Inserted plate connections.....	68
15.2.6	Gusset plate connections.....	68
15.2.7	Intersecting welded plane K-joints and N-joints.....	69
15.2.8	Plane T-joints, Y-joints and X-joints.....	72
15.2.9	Multiplanar joints.....	72
15.3	Joints of concrete-encased concrete-filled steel tubular (CFST) hybrid structures.....	72
15.3.1	Steel beam-to-column ring plate joints.....	72
15.3.2	Reinforced concrete beam-to-column joints.....	73
15.3.3	Detailing requirements of beam-to-column joints.....	74
15.3.4	Connections between steel tubes.....	75
15.4	Column bases and supporting connections.....	76
15.4.1	Column bases and supporting connections of trussed CFST hybrid structures.....	76
15.4.2	Column bases of concrete-encased CFST hybrid structures.....	79
15.5	Fatigue design of joints.....	80
15.5.1	General requirements.....	80
15.5.2	Design methods.....	80
15.5.3	Hot spot stress ranges under constant amplitude fatigue.....	81
15.5.4	Hot spot stress ranges under variable amplitude fatigue.....	81
15.5.5	Detailing requirements.....	82
<b>16</b>	<b>Construction and acceptance.....</b>	<b>83</b>
16.1	General.....	83
16.2	Fabrication and erection of steel tubes.....	83
16.2.1	General.....	83
16.2.2	Documents.....	83
16.2.3	Fabrication.....	83
16.2.4	Surface protection.....	84
16.2.5	Transportation and erection.....	84
16.3	Construction of core concrete.....	84
16.3.1	General.....	84
16.3.2	General requirements.....	84
16.3.3	Mixture design.....	85
16.3.4	Requirements of self-compacting concrete.....	85
16.3.5	Use of cement plaster.....	85
16.3.6	Placement preparation.....	85
16.3.7	Placement methods.....	85
16.3.8	Placement process.....	85
16.3.9	Treatment of post-placement holes on steel tubes.....	85
16.3.10	Requirements of limiting values of core concrete void in steel tubes.....	85
16.4	Construction of concrete encasement.....	87
16.4.1	General.....	87
16.4.2	Construction preparation.....	87
16.4.3	Workability of concrete.....	87
16.4.4	Construction order.....	87
16.5	Inspection and acceptance.....	87
16.5.1	General.....	87

## ISO/FDIS 16521:2024(en)

16.5.2 Steel structures .....	87
16.5.3 Core concrete .....	87
16.5.4 Concrete encasement .....	88
16.5.5 Documents and records .....	88
<b>Annex A (informative) Long-term load coefficients for concrete-encased circular CFST hybrid structures .....</b>	<b>89</b>
<b>Annex B (informative) Fire resistance ratings of single-chord concrete-encased circular CFST hybrid structures .....</b>	<b>93</b>
<b>Bibliography .....</b>	<b>94</b>

# iTeh Standards (<https://standards.itih.ai>) Document Preview

[ISO/FDIS 16521](https://standards.itih.ai/catalog/standards/iso/32348305-cb27-4c89-ac42-e8dadf13165b/iso-fdis-16521)

<https://standards.itih.ai/catalog/standards/iso/32348305-cb27-4c89-ac42-e8dadf13165b/iso-fdis-16521>

## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at [www.iso.org/patents](http://www.iso.org/patents). ISO shall not be held responsible for identifying any or all such patent rights.

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

This document was prepared by Technical Committee ISO/TC 71, *Concrete, reinforced concrete and prestressed concrete*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

[ISO/FDIS 16521](https://standards.iteh.ai/iso-fdis/16521)

<https://standards.iteh.ai/catalog/standards/iso/32348305-cb27-4c89-ac42-e8dadf13165b/iso-fdis-16521>

## Introduction

Concrete-filled steel tubular (CFST) hybrid structures employ CFST members as their main members, and construct with steel or reinforced concrete members or components to act compositely. They consist of trussed CFST hybrid structures, concrete-encased CFST hybrid structures, etc. The economic and environmental benefits of CFST hybrid structures have made them one of the desirable structural types for constructions in relatively tough and harsh conditions, such as mountainous areas, earthquake-prone regions, corrosive environments, and less-developed regions. They can also be used in conventional structures, such as multi-storey residential buildings and relatively short-span bridges.

iTeh Standards  
(<https://standards.itih.ai>)  
Document Preview

[ISO/FDIS 16521](https://standards.itih.ai/catalog/standards/iso/32348305-cb27-4c89-ac42-e8dadf13165b/iso-fdis-16521)

<https://standards.itih.ai/catalog/standards/iso/32348305-cb27-4c89-ac42-e8dadf13165b/iso-fdis-16521>



# Design of concrete-filled steel tubular (CFST) hybrid structures

## 1 Scope

This document provides guidelines for the design, construction, and inspection of concrete-filled steel tubular (CFST) hybrid structures. These structures can be used as main structural components like columns, girders, piers, or arches in buildings, bridges, especially in high-rise structures, long-span spatial structures, and large-scale bridges.

CFST hybrid structures can employ CFST members with a circular cross-section as their chords, and they can also use square or rectangular CFST chords.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes the requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 19338, *Performance and assessment requirements for design standards on structural concrete*

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

### 3.1

#### **concrete-filled steel tubular hybrid structure** **CFST hybrid structure**

structure in which concrete-filled steel tubular (CFST) members serve as its main members, and are in contact with and act compositely with steel or reinforced concrete members or components, including trussed CFST hybrid structure, concrete-encased CFST hybrid structure, etc.

Note 1 to entry: CFST hybrid structures more frequently employ circular CFST members due to the higher confinement effect provided by circular hollow steel tubes to the core concrete; square or rectangular CFST members can also be used when design or construction conditions require. CFST members require full composite effects between steel tubes and the core concrete. Steel tubular members using infilled concrete to only enhance their stiffness are beyond the scope of this document.

### 3.2

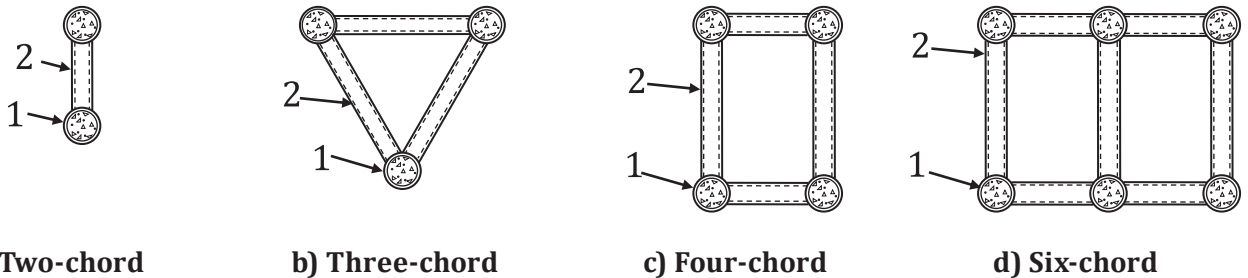
#### **trussed concrete-filled steel tubular (CFST) hybrid structure** **trussed CFST hybrid structure**

truss structure consisting of CFST chords and webs of steel tubes, CFST members or other steel profiles

Note 1 to entry: There are two-chord, three-chord, four-chord and six-chord trussed CFST hybrid structures (see [Figures 1](#) and [2](#)), and the chords are normally placed symmetrically. Trussed CFST hybrid structures generally serve as main structural members, such as truss girders, bridge piers or columns.

Note 2 to entry: During a typical construction process of cast-in-place trussed CFST hybrid structures, the steel components, such as the hollow steel tubes, are first erected; the core concrete in the chords is then placed (see [Figure 3](#)). Prefabricated CFST members can also be used in trussed CFST hybrid structures when construction conditions allow.

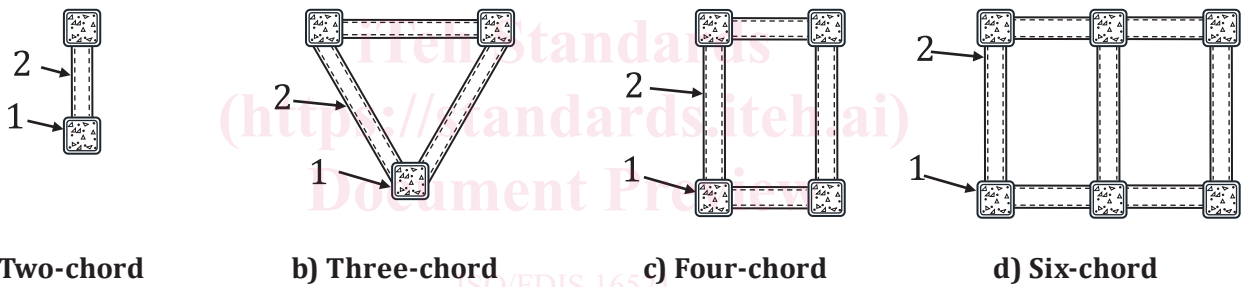
Note 3 to entry: For trussed CFST hybrid structure with rectangular CFST members, the CFST chords are generally placed to have the strong axes of their rectangular cross-sections all in parallel with the strong axis of the whole cross-section of the trussed CFST hybrid structure.



**Key**

- 1 CFST chords
- 2 webs

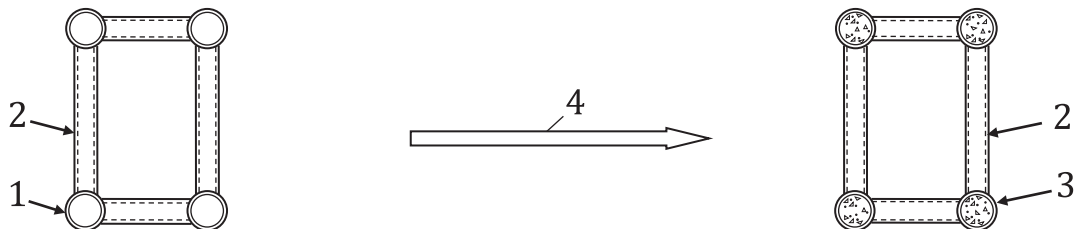
**Figure 1 — Cross-sections of trussed CFST hybrid structures with circular CFST members**



<https://standards.itech.ai/catalog/standards/iso/32348305-cb27-4c89-ac42-e8dadf13165b/iso-fdis-16521>

- 1 CFST chords
- 2 webs

**Figure 2 — Cross-sections of trussed CFST hybrid structures with square or rectangular CFST members**



**a) As hollow steel tubular structure**

**b) As trussed CFST hybrid structure**

**Key**

- 1 hollow steel tubular chords
- 2 webs
- 3 CFST chords
- 4 placement of core concrete in chords

**Figure 3 — Typical construction process of a trussed CFST hybrid structure**

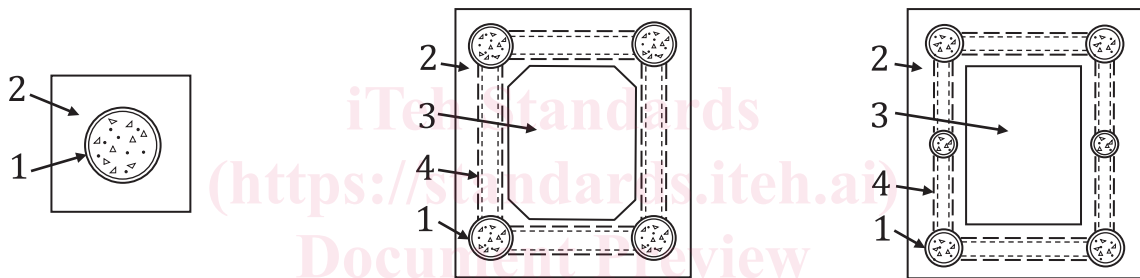
**3.3**

**concrete-encased concrete-filled steel tubular hybrid structure**

**concrete-encased concrete-filled steel tubular (CFST) hybrid structure**

structure consisting of reinforced concrete encasement and one or more embedded CFST members

Note 1 to entry: The encased CFST member(s) in the concrete-encased CFST hybrid structure can be single or multiple, as shown in Figures 4 and 5, and are normally symmetrically placed. For the single-chord type, the CFST member is placed at the centre of the cross-section with a square or rectangular concrete encasement, forming a solid cross-section. For the multi-chord type, CFST chords are placed at the corners (four-chord type) and also mid-height of the cross-section (six-chord type) of the rectangular concrete encasement; steel tubes, or CFST or other steel profiles are used as webs to connect the CFST chords; to reduce self-weight, an internal hollow section, which is octagonal or rectangular, is generally formed. The multi-chord concrete-encased CFST hybrid structures are a derivation of the trussed CFST hybrid structures, and are generally used as columns, bridge piers, arches, etc.



**a) Single-chord, solid cross-section**

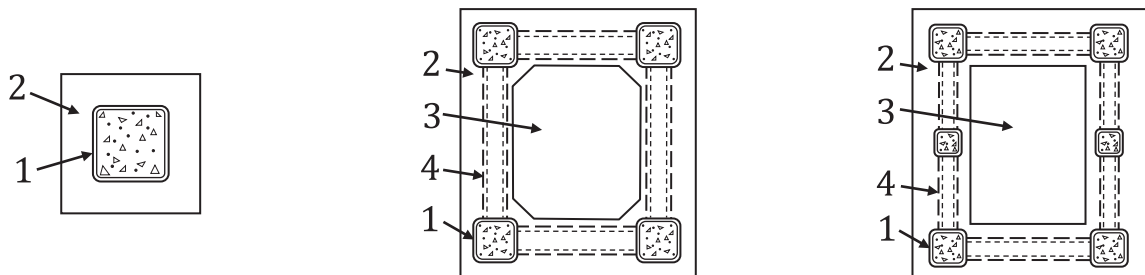
**b) Four-chord, with an internal hollow section**

**c) Six-chord, with an internal hollow section**

**Key**

- 1 CFST members
- 2 concrete encasement
- 3 internal hollow section
- 4 webs

**Figure 4 — Cross-sections of concrete-encased CFST hybrid structures with circular CFST members**



**a) Single-chord, solid cross-section**

**b) Four-chord, with an internal hollow section**

**c) Six-chord, with an internal hollow section**

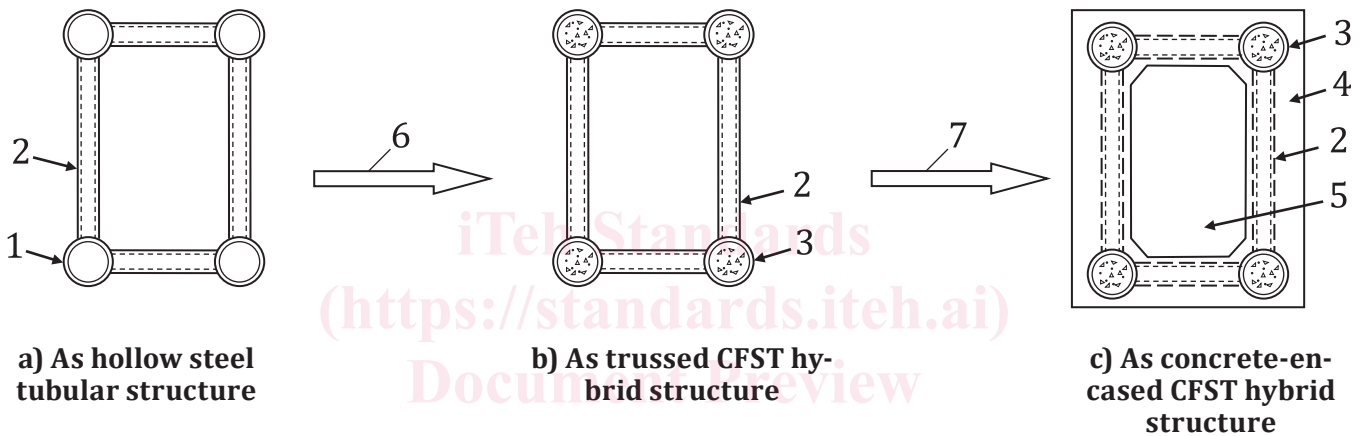
**Key**

- 1 CFST members
- 2 concrete encasement
- 3 internal hollow section
- 4 webs

**Figure 5 — Cross-sections of concrete-encased CFST hybrid structures with square or rectangular CFST members**

Note 2 to entry: A typical construction process for cast-in-place concrete-encased CFST hybrid structure consists of erection of hollow steel tubular chords and webs, placement of core concrete in chords, installation of reinforcement, and placement of concrete encasement, as shown in Figure 6. Prefabricated CFST members can also be used in concrete-encased CFST hybrid structures when construction conditions allow.

Note 3 to entry: For concrete-encased CFST hybrid structure with rectangular CFST members, the CFST chords are generally placed to have the strong axes of their rectangular cross-sections all in parallel with the strong axis of the whole cross-section of the concrete-encased CFST hybrid structure.



**Key**

- 1 hollow steel tubular chords
- 2 webs
- 3 CFST chords
- 4 concrete encasement
- 5 internal hollow section
- 6 placement of core concrete in chords
- 7 placement of concrete encasement

**Figure 6 — Typical construction process of a concrete-encased CFST hybrid structure**

**3.4**

**limiting value of initial stress in the steel tube**

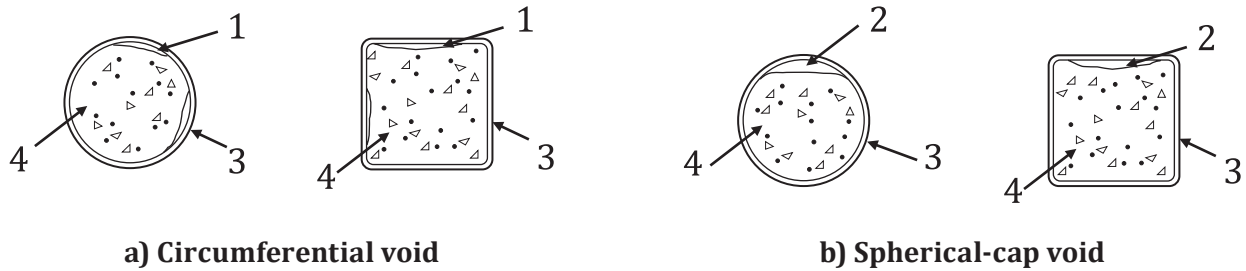
limiting value of the stress level in the steel tube before the steel tube and the core concrete in the CFST member can act together

3.5

**limiting value of core concrete void in the steel tube**

limiting value of the void ratio of the circumferential void, or the maximum height of the spherical-cap void between the steel tube and its core concrete in the CFST member

Note 1 to entry: The compactness of the core concrete in a CFST member is crucial to ensure that the steel tube and its core concrete act together. However, due to concrete shrinkage and construction issues, circumferential void [see Figure 7 a)] and spherical-cap void [see Figure 7 b)] will possibly develop in the cross-sections of vertical members and horizontal members, respectively. When the void is within a limiting value, its influence on the structural resistance is negligible. Therefore, the concept of limiting value of core concrete void in the steel tube is proposed.



**Key**

- 1 circumferential void
- 2 spherical-cap void
- 3 steel tube
- 4 core concrete

Figure 7 — Schematic diagram of core concrete voids in CFST members

3.6

**confinement factor**

ratio of the nominal compressive strength of cross-section of the steel tube to that of the core concrete in a CFST member

Note 1 to entry: Confinement factor is a representative parameter that reflects the interaction between steel tube and core concrete of the CFST member. Within the parametric ranges in this document, with the increase of the confinement factor, the steel tube provides stronger confinement to its core concrete during loading, and the strength and ductility of the CFST member increases, and vice versa. In other words, the confinement factor represents the degree of composite effects between the steel tube and its core concrete.

3.7

**equivalent slenderness ratio**

slenderness ratio converted from a trussed CFST hybrid structure to a CFST member when calculating its global stability in axial compression

**4 Symbols**

The following symbols are used generally throughout the document.

Factored actions, action effects and resistances		
Symbol	Explanation	Unit
$M$	factored bending moment	N·mm
$M_u$	bending resistance	N·mm
$N$	factored axial force	N
$N_0$	resistance of cross-section of the CFST hybrid structure to compression	N
$N_c$	resistance of cross-section of the CFST chord to compression	N

**ISO/FDIS 16521:2024(en)**

$N_{cfst}$	resistance of cross-section of the encased CFST member to compression	N
$N_{rc}$	resistance of cross-section of the concrete encasement to compression	N
$N_t$	resistance of cross-section of the CFST chord to tension	N
$N_u$	resistance of the CFST hybrid structure in axial compression	N
$V$	factored shear force	N
$V_{cfst}$	shear resistance of the encased CFST member	N
$V_{rc}$	shear resistance of the concrete encasement	N
$V_u$	shear resistance of the CFST hybrid structure	N
<b>Material properties</b>		
<b>Symbol</b>	<b>Explanation</b>	<b>Unit</b>
$E_c$	modulus of elasticity of concrete	MPa
$E_{c,c}$	modulus of elasticity of the core concrete in the CFST member	MPa
$E_{c,oc}$	modulus of elasticity of the concrete slab or concrete encasement	MPa
$E_s$	modulus of elasticity of steel	MPa
$f$	design tensile, compressive and flexural strength of steel	MPa
$f_c$	design compressive cylinder strength of concrete	MPa
$f_{ck}$	characteristic compressive cylinder strength of concrete	MPa
$f_{c,oc}$	design compressive strength of the concrete encasement	MPa
$f_l$	design tensile strength of the longitudinal reinforcement	MPa
$f_{sc}$	design compressive strength of the CFST cross-section	MPa
$f_{scy}$	characteristic compressive strength of the CFST cross-section	MPa
$f_{sv}$	design shear strength of the CFST cross-section	MPa
$f_y$	characteristic yield strength of steel	MPa
$f_{yl}$	characteristic yield strength of steel reinforcement	MPa
$G_{c,c}$	shear modulus of the core concrete in the CFST member	MPa
$G_{c,oc}$	shear modulus of the concrete slab or concrete encasement	MPa
$G_s$	shear modulus of steel	MPa
<b>Geometric parameters</b>		
<b>Symbol</b>	<b>Explanation</b>	<b>Unit</b>
$A_c$	cross-sectional area of the core concrete in the CFST member	mm <sup>2</sup>
$A_l$	cross-sectional area of the longitudinal reinforcement	mm <sup>2</sup>
$A_{oc}$	cross-sectional area of the concrete slab or concrete encasement	mm <sup>2</sup>
$A_s$	cross-sectional area of the steel tube	mm <sup>2</sup>
$A_{sc}$	cross-sectional area of the CFST member	mm <sup>2</sup>
$A_{sv}$	total cross-sectional area of stirrups	mm <sup>2</sup>
$A_v$	cross-sectional area of stirrup-confined concrete	mm <sup>2</sup>
$b$	width of the CFST hybrid cross-section	mm
$B$	width of the square or rectangular CFST member	mm
$d_r$	mean width of the circumferential void	mm
$d_s$	maximum height of the spherical-cap void	mm
$D$	outside diameter of the circular CFST member	mm
$D_i$	diameter of the core concrete in the CFST member	mm
$h$	height of the CFST hybrid cross-section	mm
$h_i$	distance along the cross-sectional height between the centroids of compression and the tension chords	mm