Data Article

Data for ultimate bearing capacity of concrete-filled steel tubular members and arches by the elastic modulus reduction method

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A B S T R A C T

Homogeneous generalized yield function is adopted in this article to calculate the ultimate bearing capacity of 93 concrete-filled steel tubular components with detailed test data, and the ratios of the ultimate bearing capacity calculated to the tested are presented. Moreover, the incremental nonlinear finite element method and elastic modulus reduction method are adopted to evaluate the ultimate bearing capacity of 11 concrete-filled steel tubular arches, 7 among which with detailed test data. The component data cover those under different loading conditions, material strength and geometric parameters, and the arch data include those under different loading conditions and rise to span ratios. The data provided are useful to investigate the strength of CFST members and arches and to demonstrate the validation of other numerical methods. The current data are considered as a complementary for the main work “Linear elastic iteration technique for ultimate bearing capacity of circular CFST arches” [1].

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Specifications Table

| Subject                      | Civil and Structural Engineering |
|------------------------------|----------------------------------|
| Specific subject area        | Concrete-filled steel tubular (CFST) structures |
| Type of data                 | Table                            |
| How data were acquired       | Formula calculation, finite element analysis and test data collected |
| Data format                  | Raw Analyzed                     |
| Parameters for data collection | Data of ultimate bearing capacity of circular CFST members and arches |
| Description of data collection | The ultimate bearing capacity of circular CFST members evaluated by homogeneous generalized yield function under different loadings and geometric parameters; The ultimate bearing capacity of CFST arches estimated by the incremental nonlinear finite element method and elastic modulus reduction method under different loading conditions and rise to span ratios. |
| Data source location         | Nanning, China                  |
|                             | Rajasthan, India                |
|                             | Beijing, China                  |
|                             | New South Wales, Australia      |
|                             | Harbin, China                   |
|                             | Fuzhou, China                   |
| Data accessibility           | With the article                |
| Related research article     | L.F. Yang, W.W. Xie, Y.F. Zhao, J. Zheng. Linear elastic iteration technique for ultimate bearing capacity of circular CFST arches. https://doi.org/10.1016/j.jcsr.2020.106135. [1] |

Value of the Data

- The data provided are useful to investigate the ultimate bearing capacity and generalized yield function (GYF) of concrete-filled steel tubular (CFST) members under different loading conditions
- The data presented are valuable to investigate the ultimate bearing capacity of CFST arches under different loading conditions
- The data may be useful to researchers interested in CFST structures.
- The data provided can serve as benchmark to validate other numerical methods for CFST structures.

1. Data

1.1. Data of ultimate bearing capacity of CFST members

The ultimate bearing capacities of 72 CFST members under axial loads, 12 CFST members under pure bending and 9 CFST members under eccentric compression with detailed test data in Lit. [2-4] are calculated by the homogeneous GYF$f_4(n_x, m_y)$:

$$f_4(n_x, m_y) = 1.0066n_x^4 + 3.4516n_x^3m_y + 6.2752n_x^2m_y^2 + 2.2168m_y^3n_x + 1.0088m_y^4 = \frac{N_x}{N_{px}}, \quad m_y = \frac{M_y}{M_p}$$

where $n_x$ and $m_y$ are normalized internal forces. $N_x$ and $M_y$ are the axial force and bending moment, respectively. $N_{px}$ and $M_p$ represent the full plastic axial force and bending moments, respectively.

The ratios of the calculated to the tested are obtained under axial loading, pure bending and eccentric compression. Then, the calculated data and the test data for CFST members under axial
1.2. Data of ultimate bearing capacity of CFST arches under in-plane loads

The CFST arches are under in-plane loading with different rise to span ratios. The arch axis equation is of parabolic curves with span length of \( L = 9 \text{ m} \). The outer diameter and wall thickness of the steel tube are 159 mm and 4.5 mm, respectively, and its yield strength \( f_y \) and elastic modulus \( E_s \) are 376.2 MPa and \( 204 \times 10^3 \text{MPa} \), respectively. The cubic compression strength \( f_{\text{cu}} \) and elastic modulus \( E_c \) of the core concrete are 41.6 MPa and \( 31.3 \times 10^3 \text{MPa} \), respectively. The ultimate bearing capacity of the CFST arches were obtained by the incremental nonlinear finite element method (INFEM), and the elastic modulus reduction method (EMRM) and test data in Lit. [5], respectively, as illustrated in Table 4.

1.3. Data of ultimate bearing capacity of a CFST arch under spatial loads

The CFST arch is under spatial loadings. The in-plane concentrated loadings are applied at five points uniformly distributed along the span while the out-of-plane concentrated loading, vertical to the arch plane and 0.1 times of the in-plane loading, is applied at the crown. The arch axis is of parabolic curve, \( y = 8x^2/75 \) with length of span 7.5 m and the height of the arch 1.5 m. The outer diameter and wall thickness of the steel tube are 121 mm and 4.5 mm, respectively, with the yield strength \( f_y = 322 \text{ MPa} \) and the elastic modulus \( E_s = 2.06 \times 10^5 \text{MPa} \). The cubic compression strength \( f_{\text{cu}} \) and the elastic modulus \( E_c \) of the core concrete are 66.7 MPa and \( 30.0 \times 10^3 \text{MPa} \), respectively. The ultimate bearing capacity of the arch obtained by the elastic modulus reduction method and the test data in Lit. [6] is 102.4 kN and 97.1 kN, respectively, with relative error of 5.5%.

1.4. Data under different material strengths and nominal slenderness ratios

The above CFST arches under in-plane loadings were taken into consideration. The nominal slenderness ratio \( \lambda \) is defined as follows:

\[
\lambda = 4L_0/D, \quad L_0 = 0.36S_g
\]

where, \( L_0 \) is an equivalent calculation length, \( S_g \) is the axis length of arch and \( D \) the outer diameter of steel tube.

The ultimate bearing capacity of the CFST arches from the INFEM, the EMRM and test data in Lit. [5] were illustrated in Table 5 under different material strengths and nominal slenderness ratios.

2. Experimental design and methods

2.1. Homogeneous GYF for CFST members

The homogeneous generalized yield function is adopted to obtain the ultimate bearing capacity of CFST components. The full plastic axial force and bending moments \( N_{px} \) and \( M_p \) in
Table 1
Ultimate loading capacity of CFST members under axial compression (kN).

| \(D\) (mm) | \(t\) (mm) | \(l\) (mm) | \(f'_c\) (MPa) | \(f'_u\) (MPa) | Test in Lit. [2] | HGYP |
|---|---|---|---|---|---|---|
| 47.28 | 1.87 | 340 | 360 | 25.15 | 215 | 158.69 |
| 47.28 | 1.87 | 340 | 360 | 28.89 | 215 | 164.08 |
| 47.28 | 1.87 | 340 | 360 | 28.22 | 210 | 163.09 |
| 47.28 | 1.87 | 340 | 360 | 27.15 | 167 | 161.53 |
| 47.28 | 1.87 | 340 | 360 | 25.33 | 178 | 158.94 |
| 47.28 | 1.87 | 340 | 360 | 22.22 | 187 | 154.79 |
| 47.28 | 1.87 | 340 | 360 | 29.02 | 145 | 164.27 |
| 47.28 | 1.87 | 340 | 360 | 28.22 | 166 | 163.09 |
| 47.28 | 1.87 | 340 | 360 | 29.73 | 176 | 165.34 |
| 47.28 | 1.87 | 340 | 360 | 28.53 | 171 | 163.55 |
| 47.28 | 1.87 | 340 | 360 | 25.2 | 168 | 158.76 |
| 47.28 | 1.87 | 340 | 360 | 22.44 | 160 | 155.07 |
| 89.32 | 2.74 | 340 | 360 | 25.15 | 610 | 484.79 |
| 89.32 | 2.74 | 340 | 360 | 28.89 | 635 | 506.13 |
| 89.32 | 2.74 | 340 | 360 | 28.22 | 630 | 502.25 |
| 89.32 | 2.74 | 340 | 360 | 27.15 | 524 | 496.11 |
| 89.32 | 2.74 | 340 | 360 | 25.33 | 494 | 485.80 |
| 89.32 | 2.74 | 340 | 360 | 22.22 | 530 | 468.73 |
| 89.32 | 2.74 | 340 | 360 | 29.02 | 540 | 506.88 |
| 89.32 | 2.74 | 340 | 360 | 28.22 | 494 | 502.25 |
| 89.32 | 2.74 | 340 | 360 | 29.73 | 560 | 511.02 |
| 89.32 | 2.74 | 340 | 360 | 28.5 | 571 | 503.87 |
| 89.32 | 2.74 | 340 | 360 | 25.2 | 582 | 485.07 |
| 89.32 | 2.74 | 340 | 360 | 22.44 | 557 | 469.91 |
| 112.56 | 2.89 | 340 | 360 | 25.15 | 754 | 692.27 |
| 112.56 | 2.89 | 340 | 360 | 28.89 | 730 | 727.57 |
| 112.56 | 2.89 | 340 | 360 | 28.22 | 745 | 721.19 |
| 112.56 | 2.89 | 340 | 360 | 27.15 | 635 | 711.04 |
| 112.56 | 2.89 | 340 | 360 | 25.33 | 720 | 693.95 |
| 112.56 | 2.89 | 340 | 360 | 22.22 | 650 | 665.32 |
| 112.56 | 2.89 | 340 | 360 | 29.02 | 686 | 728.81 |
| 112.56 | 2.89 | 340 | 360 | 28.22 | 716 | 721.19 |
| 112.56 | 2.89 | 340 | 360 | 29.73 | 681 | 735.60 |
| 112.56 | 2.89 | 340 | 360 | 28.53 | 687 | 724.14 |
| 112.56 | 2.89 | 340 | 360 | 25.2 | 700 | 692.73 |
| 112.56 | 2.89 | 340 | 360 | 22.44 | 674 | 667.31 |
| 47.28 | 1.87 | 340 | 360 | 37.6 | 250 | 177.68 |
| 47.28 | 1.87 | 340 | 360 | 40 | 225 | 181.59 |
| 47.28 | 1.87 | 340 | 360 | 37.77 | 246 | 177.96 |
| 47.28 | 1.87 | 340 | 360 | 35.68 | 177 | 174.60 |
| 47.28 | 1.87 | 340 | 360 | 36.67 | 192 | 176.18 |
| 47.28 | 1.87 | 340 | 360 | 38.31 | 165 | 178.83 |
| 47.28 | 1.87 | 340 | 360 | 31.42 | 157 | 167.91 |
| 47.28 | 1.87 | 340 | 360 | 38.23 | 156 | 178.70 |
| 47.28 | 1.87 | 340 | 360 | 36.88 | 162 | 176.52 |
| 47.28 | 1.87 | 340 | 360 | 30.88 | 190 | 167.08 |
| 47.28 | 1.87 | 340 | 360 | 32.44 | 203 | 169.49 |
| 47.28 | 1.87 | 340 | 360 | 34.66 | 194 | 172.97 |
| 89.32 | 2.74 | 340 | 360 | 37.6 | 644 | 557.96 |
| 89.32 | 2.74 | 340 | 360 | 40 | 620 | 572.57 |
| 89.32 | 2.74 | 340 | 360 | 37.77 | 650 | 558.99 |
| 89.32 | 2.74 | 340 | 360 | 35.68 | 599 | 546.35 |
| 89.32 | 2.74 | 340 | 360 | 36.67 | 620 | 552.32 |
| 89.32 | 2.74 | 340 | 360 | 38.31 | 605 | 562.27 |
| 89.32 | 2.74 | 340 | 360 | 31.42 | 603 | 520.94 |
| 89.32 | 2.74 | 340 | 360 | 38.23 | 577 | 561.78 |
| 89.32 | 2.74 | 340 | 360 | 36.88 | 552 | 553.59 |
| 89.32 | 2.74 | 340 | 360 | 30.88 | 613 | 517.76 |
| 89.32 | 2.74 | 340 | 360 | 32.44 | 599 | 526.97 |
| 89.32 | 2.74 | 340 | 360 | 34.66 | 605 | 540.22 |

(continued on next page)
Table 1 (continued)

| $D$ (mm) | $t$ (mm) | $l$ (mm) | $f_y$ (MPa) | $f'_c$ (MPa) | Test in Lit. [2] | HGYF |
|----------|----------|----------|-------------|-------------|-----------------|------|
| 112.56   | 2.89     | 340      | 360         | 37.6        | 822             | 812.07 |
| 112.56   | 2.89     | 340      | 360         | 40          | 788             | 835.71 |
| 112.56   | 2.89     | 340      | 360         | 37.77       | 801             | 813.74 |
| 112.56   | 2.89     | 340      | 360         | 35.68       | 785             | 793.25 |
| 112.56   | 2.89     | 340      | 360         | 36.67       | 755             | 802.94 |
| 112.56   | 2.89     | 340      | 360         | 38.31       | 757             | 819.05 |
| 112.56   | 2.89     | 340      | 360         | 31.42       | 735             | 751.85 |
| 112.56   | 2.89     | 340      | 360         | 38.23       | 727             | 818.26 |
| 112.56   | 2.89     | 340      | 360         | 36.88       | 747             | 805.00 |
| 112.56   | 2.89     | 340      | 360         | 30.88       | 745             | 746.64 |
| 112.56   | 2.89     | 340      | 360         | 34.66       | 758             | 761.71 |
| 112.56   | 2.89     | 340      | 360         | 34.66       | 770             | 783.29 |

Table 2
Ultimate loading capacity of CFST members under pure bending (kN·m).

| $D$ (mm) | $t$ (mm) | $l$ (mm) | $f_y$ (MPa) | $f'_{c,u}$ (MPa) | Test in Lit. [3] | HGYF |
|----------|----------|----------|-------------|-------------------|-----------------|------|
| 140      | 3        | 840      | 235         | 51.5              | 19.8            | 21.17 |
| 140      | 3        | 840      | 235         | 51.5              | 21.6            | 21.17 |
| 140      | 3        | 1680     | 235         | 51.5              | 21.5            | 21.17 |
| 140      | 3        | 840      | 235         | 51.5              | 22.1            | 21.17 |
| 140      | 3        | 1680     | 235         | 51.5              | 20.7            | 21.17 |
| 140      | 3        | 1680     | 235         | 51.5              | 20.4            | 21.17 |
| 180      | 3        | 900      | 235         | 62.6              | 33.9            | 39.88 |
| 180      | 3        | 900      | 235         | 62.6              | 34.9            | 39.88 |
| 180      | 3        | 1800     | 235         | 62.6              | 32.2            | 39.88 |
| 180      | 3        | 1800     | 235         | 62.6              | 40.6            | 39.88 |
| 180      | 3        | 1800     | 235         | 62.6              | 36.3            | 39.88 |

Table 3
Ultimate loading capacity of CFST members under eccentric compression (kN).

| $D$ (mm) | $t$ (mm) | $l$ (mm) | $e$ (mm) | $f_y$ (MPa) | $f'_c$ (MPa) | Test in Lit. [4] | HGYF |
|----------|----------|----------|----------|-------------|-------------|-----------------|------|
| 240      | 6        | 720      | 120.0    | 489         | 31.5        | 1277            | 1331.74 |
| 360      | 6        | 1080     | 60.1     | 498         | 31.5        | 4294            | 4228.85 |
| 480      | 6        | 1440     | 240.0    | 468         | 31.5        | 3323            | 3066.18 |
| 600      | 6        | 1800     | 300.0    | 517         | 31.5        | 4590            | 4434.22 |
| 240      | 6        | 720      | 120.0    | 489         | 59          | 1438            | 1517.41 |
| 360      | 6        | 1080     | 180.0    | 498         | 59          | 2537            | 2638.99 |
| 480      | 6        | 1440     | 240.0    | 468         | 59          | 3895            | 3719.44 |
| 300      | 12       | 900      | 150.0    | 479         | 31.5        | 3683            | 2816.71 |
| 480      | 12       | 1440     | 240.0    | 489         | 31.5        | 5135            | 5326.95 |

Table 4
Ultimate bearing capacity of the arches with different rise to span ratios.

| Loading position | rise to span ratio | Test/kN in Lit. [5] | INFEM /kN | EMRM/kN |
|------------------|-------------------|---------------------|------------|---------|
| span             | 1/4               | 132.5               | 140.5      | 130.9   |
|                  | 1/7.5             | -                   | 149.1      | 144.3   |
|                  | 1/6               | 163.5               | 158.1      | 149.9   |
|                  | 1/4.5             | 165                 | 167.1      | 151.7   |
|                  | 1/3               | -                   | 174.3      | 148.1   |
| Crown            | 1/9               | 103.4               | 113.1      | 99.4    |
|                  | 1/7.5             | -                   | 116.5      | 101.0   |
|                  | 1/6               | 110.7               | 119.9      | 103.9   |
|                  | 1/4.5             | 106.8               | 123.0      | 105.0   |
|                  | 1/3               | -                   | 124.6      | 103.7   |
Table 5
Ultimate bearing capacity of the arches with different material strengths and nominal slenderness ratios.

| Loading position | Nominal slenderness ratio | Test/kN in Lit. [5] | INFEM /kN | EMRM/kN | Design material strength | Characteristic material strength |
|-------------------|---------------------------|---------------------|-----------|---------|--------------------------|-------------------------------|
| Crown             |                           |                     |           |         |                          |                               |
| 20                | 40                        | 60                  | 80        | 84.12   | 132.5                    | 140.5                        | 130.9                        | 161.8                        | 387.9                        | 278.8                        | 208.5                        | 162.8                        | 140.6                        | 120.7                        | 105.6                        | 93.8                         | 84.3                         | 76.6                         | 375.6                        | 232.9                        | 166.0                        | 128.6                        | 122.9                        | 106.8                        | 90.1                         | 77.9                         | 68.6                         | 61.3                         | 55.4                         |
| 1/4 span          |                           |                     |           |         |                          |                               |
| 20                | 40                        | 60                  | 80        | 84.12   | 103.4                    | 113.1                        | 99.4                         | 122.9                        | 304.2                        | 232.9                        | 166.0                        | 128.6                        | 122.9                        | 106.8                        | 90.1                         | 77.9                         | 68.6                         | 61.3                         | 55.4                         |

Eq. (2) are determined on the basis of the material and geometric parameters of the CFST members. Then, substituting $n_x$ and $m_y$ into Eq. (1), the ultimate bearing capacity of CFST members can be determined conveniently by solving the $N_x$ or $M_y$ from the equation $\tilde{f}_4(n_x, m_y) = 1$ in case of the member under axial loading or pure bending, respectively. If the CFST member is exposed to eccentric compression $N_x$ with eccentricity $e$, $M_y$ is defined as $M_y = N_x \cdot e$. Then substituting $n_x$ and $m_y$ into Eq. (1), the ultimate bearing capacity of the member can similarly be evaluated by solving the $N_x$ from the equation $\tilde{f}_4(n_x, m_y) = 1$.

2.2. Elastic modulus reduction method for arches

The incremental nonlinear finite element method and elastic modulus reduction method are used to evaluate the ultimate bearing capacity of CFST arches. As the incremental nonlinear finite element method is commonly used and well-known to researchers, only the main procedures of elastic modulus reduction method are introduced as follows:

Step 1: Conduct linear elastic finite element analysis of CFST arches

The linear elastic finite element model is developed to calculate the internal forces for CFST arches.

Step 2: Identification of highly-stressed elements

The element bearing ratio $r_k^e$ of each element in CFST arches is determined by the homogeneous GYF under combined actions of axial force and bending moment:

$$r_k^e = \sqrt[4]{\tilde{f}_4(n_x, m_y)}$$  \hspace{1cm} (4)

Then the reference element bearing ratio reads:

$$r_k^0 = r_k^\text{max} - d_k(r_k^\text{max} - r_k^\text{min})$$  \hspace{1cm} (5)

where $r_k^\text{max}$ and $r_k^\text{min}$ are the maximum and minimum element bearing ratios in the $k^{th}$ iteration, respectively, and $d_k$ denotes the uniformity of the element bearing ratio.
If $r_k^e > r_k^0$, the element $e$ is considered as highly-stressed one in $k^{th}$ iteration, then its elastic modulus should be reduced.

**Step 3: Elastic modulus reduction**
The Elastic moduli of highly-stressed elements in CFST arches are reduced as:

$$E_{k+1}^e = \begin{cases} 
\frac{2r_k^0}{(e_k^0)^2 + (e_k^0)^2} & r_k^e > r_k^0 \\
E_k^e & r_k^e \leq r_k^0
\end{cases} \tag{6}$$

where $E_k^e$ and $E_{k+1}^e$ are the elastic moduli of the element $e$ in the $k^{th}$ and $(k+1)^{th}$ iterations, respectively.

**Step 4: Evaluation of ultimate bearing capacity of CFST arches**
The ultimate bearing capacity $P_k^L$ for $k^{th}$ iterative step is determined according to the maximum element bearing ratio, and reads:

$$P_k^L = P_0 / r_k^\text{max} \tag{7}$$

The above iteration process is repeated until the limit loads between two adjacent iterative steps meet the following convergence criterion:

$$\left| \left( P_k^L - P_{k-1}^L \right) / P_{k-1}^L \right| \leq \varepsilon, \quad k \geq 2 \tag{8}$$

where $\varepsilon$ is the allowable error.

If the criterion of convergence is satisfied at the $m^{th}$ iterative step, the ultimate bearing capacity of the CFST arch writes:

$$P_L = P_m^L \tag{9}$$

**Declaration of Competing Interest**

This manuscript is original and not published or being considered for publication elsewhere. It will not be copyrighted, submitted, or published elsewhere while acceptance by Date in Brief is under consideration. All authors have directly participated in the research work of this manuscript.

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**Supplementary materials**

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.dib.2020.105994.

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