Performance of Chinese 701 Aluminum Alloy L-shaped Member under Axial Compression

Xiaoguang Hu1*, Yongfeng Cheng1, Zhijie Cui2, Haijun Xing1 and Xiaonong Guo3

1 China Electric Power Research Institute, Beijing, 100055, China
2 Aerospace Research Institute of Materials and Processing Technology, Beijing, 100076, China
3 College of Civil Engineering, Tongji University, Shanghai, 200092, China
*Corresponding author’s e-mail: dkyhxg@163.com

Abstract. Chinese 701 aluminum alloy is a new type of building material with excellent performance. Compared with the traditional 6061-T6 aluminum alloy, 701 aluminum alloy has higher strength, better ductility and has a broad application prospect in towers. Firstly, the test of 24 Chinese 701 aluminum alloy L-section axial compression members was finished, and the ultimate bearing capacity and failure mode of the component were obtained; then a numerical analysis model was established and verified by the experimental results. Then, a large number of numerical analyses have been completed considering the influence factors such as slenderness ratio, section size, and initial bending. Finally, the experimentally measured stability coefficients were compared with the stability coefficients calculated by the Chinese code. The comparison results show that the overall stability bearing capacity of the 701 aluminum alloy L-shaped axial compression member can be calculated using the formula in Chinese "Aluminum Structure Design Code".

1. Introduction

Aluminum alloys have been widely used in various building structures because of their light weight, high specific strength, good corrosion resistance and beautiful appearance. Chinese code has given the formula for calculating the axial compression members of aluminum alloys, due to the variety of grades and cross sections of aluminum alloys, at present, many scholars have done a lot of experimental research, finite element simulation and theoretical analysis on the buckling behavior of aluminum alloy members. Zhu Jihua [1-2] systematically studied 6061-T6 and 6063-T5 aluminum alloy tubes with circular and rectangular hollow sections, and proposed the design method of accurately predicting the welding and non-welding columns of aluminum alloy. Liu Mei [3-4] investigated the buckling behavior of aluminum alloy members with irregular cross-section through experimental and numerical studies. Wang Yujin [5] and Adeoti [6] compared the experimental results of 6082-T6 aluminum alloy members with the buckling strength predicted by the current code. It is shown that the calculated results of Rasmussen-Ronal formula [7] are the closest to the experimental results. The local buckling strength and post-buckling strength of aluminum alloy I-section short columns were studied by Yuan Huanxin [8]. L-shaped cross-section members are the most commonly used cross-section types of transmission towers, which are mainly subjected to axial and eccentric pressures. Compared with 6061-T6 aluminum alloy, 701 Aluminum Alloy of China has higher strength and better ductility, and has a wide application prospect in transmission tower. This paper is
to study the buckling behavior of 701 Aluminum Alloy L-section axial compression members and to calculate its ultimate bearing capacity accurately.

2. Test of member in Compression

2.1. Specimen design
In this paper, 24 aluminum alloy L-shaped axial compression members were tested under axial load. The two specifications of testing component are L50×5 and L80×6, respectively. In order to study the influence of slenderness ratio on the bearing capacity of axial compression members, 4 slenderness ratios were set up. The detailed section diagram of the component is shown in figure 1.

![Figure 1. Section size](image)

2.2. Material Property
According to GB/T 228-2010, 6 tensile specimens were obtained by Longitudinal sampling on L-shaped members, and the properties of 701 aluminum alloy were obtained by tensile test. The tensile specimens after fracture are shown in figure 2. The Stress–strain curve of all specimens is shown in figure 3. The transverse axes of the specimens are the strains and the longitudinal axes are the stresses in MPa. The elastic modulus $E$ is 68347.5 MPa, nominal yield strength $F_{0.2}$ is 423.7 MPa and ultimate strength $F_u$ is 452.2 MPa.

![Figure 2. Tensile specimen after breaking](image)  
![Figure 3. Stress-strain curves of all tensile specimens](image)

2.3. Test results of Failure Mode and Ultimate Bearing Capacity
A total of 24 L-shaped axial compression members of 701 aluminum alloy have been completed. The ultimate bearing capacity and failure modes of all the specimens are summarized in table 1. When the slenderness ratio of the member is small, the member will be bent and twisted, and when the slenderness ratio is large, the member will be bent and unstable. The failure mode of the typical member is shown in figure 5 and figure 6.
Table 1. Summary of measured ultimate bearing capacity of axial compression members.

| Specimen number | Measured slenderness | Measured bearing capacity (kN) | failure mode         |
|-----------------|----------------------|-------------------------------|----------------------|
| L50-701-40A     | 48.16                | 119.63                        | Bending and torsion buckling |
| L50-701-40B     | 48.05                | 120.81                        |                       |
| L50-701-40C     | 48.05                | 108.25                        |                       |
| L50-701-80A     | 88.60                | 42.65                         |                       |
| L50-701-80B     | 88.71                | 39.98                         |                       |
| L50-701-80C     | 88.66                | 40.54                         |                       |
| L50-701-120A    | 128.86               | 19.71                         |                       |
| L50-701-120B    | 128.91               | 19.34                         |                       |
| L50-701-120C    | 128.82               | 19.59                         |                       |
| L50-701-160A    | 169.20               | 10.07                         |                       |
| L50-701-160B    | 169.31               | 10.38                         |                       |
| L50-701-160C    | 169.21               | 11.75                         |                       |
| L80-701-40A     | 60.57                | 167.19                        |                       |
| L80-701-40B     | 60.41                | 173.29                        |                       |
| L80-701-40C     | 60.66                | 181.12                        |                       |
| L80-701-60A     | 65.48                | 142.17                        |                       |
| L80-701-60B     | 65.85                | 142.67                        |                       |
| L80-701-60C     | 66.34                | 139.74                        |                       |
| L80-701-80A     | 85.47                | 80.19                         |                       |
| L80-701-80B     | 85.64                | 91.15                         |                       |
| L80-701-80C     | 85.34                | 81.56                         |                       |
| L80-701-100A    | 105.76               | 58.75                         |                       |
| L80-701-100B    | 105.84               | 58.75                         |                       |
| L80-701-100C    | 105.98               | 58.01                         |                       |

2.4. Measured Load-strain Curve

The load-strain curves of some axial compression members are drawn in figure 4. At the initial stage of loading, the strain of the member increases linearly with the increase of load. For bend Buckling members, when the load is large, the rate of compressive strain on one side of the member increases gradually, while the compressive strain on the other side changes into tensile strain. The results show that the bending occurs before the peak load. For flexural-torsional Buckling members, when the load is large, the rate of increase of compressive strain on one side of the member increases gradually, and the rate of increase of compressive strain on the other side decreases gradually until the negative increase. When the peak load comes into being, the moment moment moment of flexural-torsional buckling failure occurs.
3. Numerical simulation

The boundary conditions of the finite element model are the same as those set up in the experiment. The influence of material nonlinearity and geometric nonlinearity is considered in the calculation. The constitutive relation of aluminum alloy is described by Ramberg-Osgood model and Steinhardt's suggestion. The mechanical properties are determined according to the tensile test results.

The failure modes and ultimate bearing capacity of flexural-torsional Buckling and flexural-bend buckling members were analyzed. The FE model of the failure mode is shown in figure 5 and figure 6. Table 2 and table 3 presents the comparison of the finite element bearing capacity $P_{FE}$ and the measured bearing capacity $P_u$ of the flexural-torsional buckling and flexural-bend buckling members under axial compression. The results show that the finite element simulation results are in good agreement with test, with an average deviation of 8.94% and 4.92%. Therefore, the FE model can accurately simulate the failure of aluminum alloy axial compression members.

| Specimen number | Measured bearing capacity $P_u$/kN | Numerical bearing capacity $P_{FE}$/kN | Measured Stability Factor $\phi_u$ | Numerical Stability Factor $\phi_{FE}$ | Error |
|-----------------|-------------------------------|----------------------------------|----------------------------------|----------------------------------|-------|
| L50-701-40A     | 119.63                        | 118.19                           | 0.583                            | 0.576                            | 1.22% |
| L50-701-40B     | 120.81                        | 119.58                           | 0.584                            | 0.578                            | 1.03% |
| L50-701-40C     | 108.25                        | 119.57                           | 0.523                            | 0.578                            | -9.47%|
| L80-701-40A     | 167.19                        | 153.16                           | 0.336                            | 0.378                            | 9.16% |
| L80-701-40B     | 173.29                        | 153.28                           | 0.382                            | 0.378                            | -9.47%|
| L80-701-40C     | 181.12                        | 152.66                           | 0.365                            | 0.378                            | 13.05%|
| L80-701-60A     | 142.17                        | 132.49                           | 0.321                            | 0.332                            | 7.31% |
| L80-701-60B     | 142.67                        | 129.40                           | 0.375                            | 0.328                            | 10.26%|
| L80-701-60C     | 139.74                        | 126.62                           | 0.306                            | 0.323                            | 10.36%|
Table 3. Comparison of ultimate bearing capacity of bending instability members

| Specimen number | Measured bearing capacity $P_u$/kN | Numerical bearing capacity $P_{FE}$/kN | Measured Stability Factor $\varphi_u$ | Numerical Stability Factor $\varphi_{FE}$ | Error |
|-----------------|-----------------------------------|---------------------------------------|--------------------------------------|------------------------------------------|-------|
| L50-701-80A     | 42.65                             | 40.66                                 | 0.207                                | 0.197                                    | 4.90% |
| L50-701-80B     | 39.98                             | 40.53                                 | 0.194                                | 0.197                                    | -1.35%|
| L50-701-80C     | 40.54                             | 40.55                                 | 0.197                                | 0.197                                    | -0.02%|
| L50-701-120A    | 19.71                             | 19.39                                 | 0.097                                | 0.095                                    | 1.66% |
| L50-701-120B    | 19.34                             | 19.51                                 | 0.094                                | 0.095                                    | -0.86%|
| L50-701-120C    | 19.59                             | 19.61                                 | 0.095                                | 0.095                                    | -0.13%|
| L50-701-160A    | 10.07                             | 11.56                                 | 0.049                                | 0.056                                    | -12.87%|
| L50-701-160B    | 10.38                             | 11.66                                 | 0.050                                | 0.056                                    | -10.96%|
| L50-701-160C    | 11.75                             | 11.44                                 | 0.058                                | 0.056                                    | 2.73% |
| L80-701-80A     | 80.19                             | 83.51                                 | 0.201                                | 0.209                                    | -3.97%|
| L80-701-80B     | 91.15                             | 83.55                                 | 0.227                                | 0.208                                    | 9.10% |
| L80-701-80C     | 81.56                             | 84.42                                 | 0.202                                | 0.209                                    | -3.39%|
| L80-701-100A    | 58.75                             | 55.05                                 | 0.148                                | 0.139                                    | 6.73% |
| L80-701-100B    | 58.75                             | 54.44                                 | 0.150                                | 0.139                                    | 7.92% |
| L80-701-100C    | 58.01                             | 54.08                                 | 0.148                                | 0.138                                    | 7.28% |

3.1. Numerical analysis
In order to further analyze the buckling behavior of 701 Aluminum Alloy l-shaped axial compression members, a large number of finite element models have been established, the influences of initial geometric imperfections, 5 kinds of cross-section specifications and different slenderness ratios are considered. The initial geometric imperfection is set to L/1000 and the mechanical properties are obtained by tensile test. There were five specifications, which are L50×5, L80×6, L100×8, L125×12 and L160×14 respectively. Considering 120 slenderness ratios, 600 finite element models can be obtained for each section. The results of the finite element analysis are shown in figure 7.

![Figure 7. Comparison of numerical results with Euler and code curves](image)

4. Theoretical formula
Figure 8 shows a comparison of all the numerical results with the curves of Euler's formula and GB 50429-2007, code for structural design of Aluminium Alloys. Fig. 9 shows comparison of all the test results with the curves of Euler's formula and the code GB50429-2007. The results of numerical analysis and test data are in good agreement with the column curve of weak hardening aluminum alloy in Chinese code. The average value of the ratio of the test data to the standard formula is 1.088, the standard deviation is 0.071, and the Coefficient of variation is 0.065, which shows that the standard
formula is an effective and accurate method for the ultimate bearing capacity of l-shaped axial compression members of 701 aluminum alloy made in China.

Figure 8. Comparison of test results with Euler and code curves

5. Conclusion
(1) Compared with the traditional 6061-T6 aluminum alloy, the Chinese 701 Aluminum Alloy has higher nominal yield strength and better ductility;
   (2) The buckling modes of l-shaped axial compression members are mainly flexural-torsional buckling and flexural-buckling, while the members with small slenderness ratio are usually flexural-torsional buckling and those with large slenderness ratio are flexural-buckling;
   (3) The results of the test and numerical analysis show that the global stability capacity of domestic 701 aluminum alloy l-shaped axial compression members can be calculated by the formula of Chinese code for the structural design of Aluminum Alloy.

Acknowledgments
This study was financially supported by "National Key R&D Program of China" (Grant No. 2018YFC0809400), Science and technology project of State Grid Corporation of China.

References
[1] Zhu, J.H., Young, B. (2006) Aluminum alloy tubular columns—Part I: Finite element modeling and test verification. Thin-Walled Structures, 44(9): 969–985.
[2] Zhu, J.H., Young, B. (2008). Numerical investigation and design of aluminum alloy circular hollow section columns. Thin-Walled Structures, 46(12): 1437–1449.
[3] Liu, M., Zhang, L.L., Wang, P.J., Chang, Y.C. (2015) Buckling behaviors of \section{section} aluminum alloy columns under axial compression. Engineering Structures, 95: 127–137.
[4] Liu, M., Zhang, L.L., Wang, P.J., Chang, Y.C. (2015) Experimental investigation on local buckling behaviors of stiffened closed-section thin-walled aluminum alloy columns under compression. Thin-Walled Structures, 94: 188–198.
[5] Wang, Y.J., Fan, F., Lin, S.B. (2015) Experimental investigation on the stability of aluminium alloy 6082 circular tubes in axial compression. Thin-Walled Structures, 89: 54–66.
[6] G.O. Adeoti, Fan, F. (2015) Stability of 6082-T6 aluminum alloy columns with H-section and rectangular hollow sections. Thin-Walled Structures, 89: 1–16.
[7] K.J.R. Rasmussen, J. Rondal. (2000) Strength curves for metal columns. Engineering Structures, 23: 1505–1517.
[8] Yuan, H.X., Wang, Y.Q., Chang, T., Du, X.X., Bu, Y.D., Shi, Y.J. (2015) Local buckling and postbuckling strength of extruded aluminium alloy stub columns with slender I-sections. Thin-Walled Structures, 90: 140–149.