Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium 2009, Valencia
Evolution and Trends in Design, Analysis and Construction of Shell and Spatial Structures
28 September – 2 October 2009, Universidad Politecnica de Valencia, Spain
Alberto DOMINGO and Carlos LAZARO (eds.)

Progresses of Loading behavior of Bolted Joints Used in Aluminum Alloy Structures

Han XU   Xiaonong GUO   Yongfeng LUO

Department of Building Engineering, Tongji University, Shanghai 200092, China
xuhan84@sohu.com

Abstract

The current development of the static loading behavior and design methods of bolted joints used in aluminum alloy structures are summarized in this paper. The review includes the progresses of the experimental investigation, collapse mechanism, loading behavior, load-bearing capacity, numerical simulation and design methods of the bolted joints. The loading behavior of the bolted joints used in aluminum alloy structures has been widely investigated in many developed countries till now. Some suitable design methods and/or directions are obtained and adopted in current related specifications. Then because of almost rare application in civil engineering, the loading behavior and the design methods of bolted joints of the aluminum alloy structures are not investigated deeply and thoroughly in China. And the collapse mechanism of the joints has not been thoroughly understood yet. No applicable standards or references can be adopted for actual design now. Therefore, both numerical analysis and experimental investigation of the bolted joints used in aluminum alloy structures need to be conducted further. It can provide a theoretical basis for aluminum alloy structure design.

Keywords: aluminum alloy structure, bolted joint, collapse mechanism

1. Introduction

The aluminum alloy has been widely used in civil engineering since about the middle of the 20th century. However, it did not emerge in China civil engineering until the 1990s. Nowadays, more than ten large-scale space aluminum structures have been built in China (Shen [33]), whereas there is restricted for future development of the aluminum structures because of lack of suitable specifications.

Based on requirement of site installing and fatigue loading, bolted or riveted joints are the best choice for aluminum alloy structures. Besides, it is crucial that the strength of aluminum alloy may be greatly reduced if welding(Sharp [37]). As a consequence, the bolt fastening is more widespread in the aluminum alloy structures than welded connection. In bolted aluminum frameworks, it has been estimated that the weight of the joints is about 10% of the total weight of the structure (Cullimore [8]).

Both aluminum alloy and steel are metal. Accordingly, the joint design methods are similar between aluminum alloy structures and steel structures (Cheng [7]). In the case that a single bolt subjects to shear or tension or combination of shear and tension, the formulas adopted in steel structures are directly employed in the design specifications of aluminum structures in many countries (ECCS [11]). However, the deformation of aluminum is more remarkable than that of steel since the elastic modulus of aluminum is approximately one-third that of steel (UNI [39]). For example, compared with steel, the prying force of a T-stub connection in aluminum alloy is larger. Therefore, an intensive study about the behavior differences of bolted joints between aluminum alloy and steel is necessary.

Usually, the σ-ε behavior of aluminum alloy, obtained from tension tests, cannot be simplified as a perfectly elastic-plastic behavior as is done for steel. More complex models have to be used. As early as 1939, the well-known Ramberg-Osgood model was proposed (Ramberg and Osgood [31])

$$\varepsilon = \frac{\sigma}{E} + (\frac{\sigma}{B})^n \tag{1}$$

where ε and σ are strain and stress, respectively; E is elastic modulus, B and n are parameters based on tests.

A convenient method was suggested by SteinHardt (SteinHardt [35]) for the determination of the parameter n in 1971.

$$10n = f_{0.2}(MPa) \tag{2}$$

The proposal is widely used, because it is simple and coincides with the actual properties of aluminum alloy. And it is applicable for aluminum alloys made in China (Guo [14]).

Some other models were suggested, such as the index model, which was applied in the numerical analysis of T-stub joints by Mazzolani (Berstad [5])

For $\sigma \le \sigma_0$, $$\sigma = E\varepsilon \tag{3}$$

For $\sigma = \sigma_0$, $$\sigma = \sigma_0 + \alpha\left[1 - \exp\left(-\gamma\varepsilon_p\right)\right] \tag{4}$$

Where σ_0 is the stress at proportional limit obtained from uniaxial tests; ε_p is the plastic strain. Material parameters α and γ determine the magnitude of the strain hardening and the shape of the hardening curve, respectively.

Most researches about bolted joints in aluminum alloy structures focus on difficult issues, such as fatigue behavior and local stability, in developed countries at present. A large number of experimental investigation (Atzori [3], Lazzarin [19], LABEIN [20] and [21]) in some European projects has improved the knowledge about the fatigue behavior of aluminum bolted joints as well as the calculation methods and design standards(Atzori [4], Lazzarin [22] and [23]). For example, the American specification (Aluminum [2]) gives practical provisions about fatigue design of bolted connections and the British standard BS 8118 gives two fatigue curves for design of aluminum bolted joints.

2. Shear resistance

2.1. Collapse mechanisms of aluminum joints under shear

The failure mechanisms of ordinary bolt joints under shear in aluminum alloy structures are consistent with those in steel structures. The failure modes include shear failure of bolts, excessive ovalisation of holes, shear rupture, tension failure of the plate and block shear failure of a bolt group (Kissell and Ferry [15]). The design method used in steel structures corresponding each failure mode is transformed for design of aluminum structures in Europe and the United States (Eurocode3 [9], AISC [1]). A formula of the compression strength of a bolt hole was fitted by means of numerical analysis. If the ratio of end distance e to aperture d_0 is between 1.5 and 4.0 (Zhang [41], Shi [34]), the strength is

$$f_c^b = \sigma_c / \gamma_m = \left[0.85e / d_0 + 0.5\right] f_u / \gamma_m \tag{5}$$

The material partial coefficient γ_m of aluminum alloy is 1.2 in BS8118 ([6]) and 1.25 in EC9 ([10]). In American specifications, a safety factor 2.34 is adopted in bolted connections of building structures. The resistance partial factor is 1.8 according as the average of load partial factor is 1.3 (Aluminum Association [16])**.** The coefficient γ_m is 1.8 (Shi [34]) , and the result is conservative compared with that of EC9 or BS8118.

2.2. Friction joints with high-strength steel bolts

Friction joints are permitted only when high-strength steel bolts are used, because of pre-tension requirement in bolts. The design strength of a friction joint is determined by pre-tension, number of bolts, partial coefficient and friction coefficient. Based on test results, the influence elements of the conventional slip factor are suggested (Ramirez [32]). The conventional slip factor does not depend on the number of bolts in the joint, nor the plate cover ratio. However, it depends mainly on the sum thickness of the joint-plates. And it increases with the total thickness ($\sum t$) of joint plates till $\sum$t = 33mm approximately. A similar consequence is given in reference (Cullimore [8]).

2.3. Determination of the net area

When the bolts are not arranged in order, definition of the critical section may be difficult. The critical section is determined on the basis of the minimum ultimate load-bearing capacity of the plate subjected to tension and shear. It is a function of the possible failure lines. From a empirical point of view (Federico [13]), failure always occurs along the shortest line going through several holes.

The detail calculation of the net area A_{net} of the critical section is not mentioned in EC9. It is prescribed in reference (Aluminum Association [2]). The net area A_{net} of a joint-plate is the sum of products of the thickness and the least net width of each element (Figure 1).

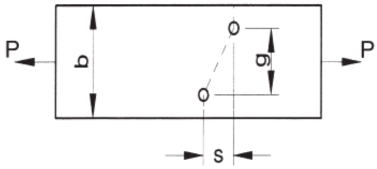

Figure 1: The net area of a strap section

For a hole chain extending in a diagonal or zigzag line in a connection plate, the net width of the plate shall be obtained by deducting the sum width of all holes in the chain from the gross plate width, and adding, for each gage space in the chain, the quantity $s^2/4g$.

$$A_{net} = \left(b - 2d + \frac{s^2}{4g} \right) t \tag{6}$$

Where *s* is the center-to-center distance, parallel to *P*, of adjacent holes; *g* is the transverse center-to-center distance between adjacent bolt lines; *d* is the hole diameter; *b* and *t* are gross width and thickness of the plate (Figyre 1).

2.4. Load bearing capacity reduction factor for long joints

In the case of bolt group connection, the shear force of each bolt generally is assumed equal. As a matter of fact, the distribution of shear force among the bolts in elastic stage is of U-shaped instead of uniform along the direction of the external force (Kulak [16]). The bolts in joint edges may be damaged firstly when the joint suffers a larger load, then follows by the destruction of the other bolts in turn, and finally the joint fails entirely. Therefore, the design strength of a bolt in long joints should be reduced by multiplying a reduction coefficient.

The non-uniform load-bearing coefficient of aluminum bolted connections in elastic stage was compared with that of steel bolted connections (Shi [34]). Both cases were analyzed under different connection lengths. The non-uniform degree of load-bearing in aluminum alloy connections increases significantly with increase of the connection length, and is greater than that in steel joints.

According to EC3, when the distance L_j between centres of bolts in two edges, measured in the direction of the external force, is more than 15*d*, the design shear resistance of all bolts should be reduced by multiplying a reduction factor β, given by

$$\beta = 1.075 - 0.005 L_j / d \geq 0.75 \tag{7}$$

Where *d* is the bolt nominal diameter.

The same mathod has been adopted in EC9 for analysis of aluminum alloy joints. And a similar provision about the total thickness of the joint plates is proposed in aluminum design manual (Aluminum Association [2]). If the total thickness of the aluminum joint plates exceeds 4.5*d*, the shear strength shall be reduced, divided by $[1/2+t/(9d)]$, in which *t* is the total thickness. According to the code for design of steel structures (National [28]), when L_j is more than 15d, the reduction factor β should be calculated as follows

$$\beta = 1.1 - L_j / (150d) \geq 0.7 \tag{8}$$

Experiments about the shear resistance of group bolts have proved that it is safe to adopt the reduction factor given by EC3 and GB50017 in design of of aluminum alloy structures (Li [18]). This may be owing to the larger room of plastic deformation provided in aluminum bolts, because the deformation of holes in aluminum alloy plates is more remarkable than that in steel plates. And it is conducive to the expected uniform distribution of shear forces in long joints during ultimate limit stage.

3 . T-stub connection

3.1. Researches on the T-stub connection of steel structures

T-stub is one of the simplest ways to connect two plates orthogonally, where the bolts are subjected to tension predominantly. The behavior of T-stubs has been widely investigated in steel joints. Several suitable design methods have been proposed in the current specifications for the prediction of joints behavior (Figure 2) (Kato [17], Nair [30], Wang [40]). However, the current situation of T-stub connections of aluminum alloy is in the early stage of development. In China, there are no definitive conclusions about the prediction of the structural behavior and design specifications of aluminum alloy T- stubs.

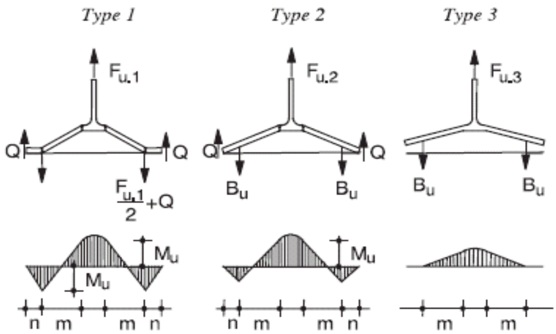

Figure 2: Failure mechanism of steel T-stubs according to EC3-Annex J

Considering the unfavorable effects of prying on joints, the design strength should be multiplied by 0.8 in ordinary bolt joints in China design code. This approach appears to be simple, but it fails to distinguish different collapse mechanisms and may be tend to unsafe when a thin junction panel is employed. Different formulas for each failure mode are provided in EC3, and the smallest strength correponding to three possible failure modes should be taken as the tension resistance of a T-stub.

3.2. Collapse mechanisms for aluminum T-stubs

For an aluminum alloy T-stub, it is necessary to consider additional failure mechanisms of components compared with a steel T-stub (Matteis [24]). Firstly, the relatively lower material ductility of the T-stub flanges can limit the plastic deformation, and the equilibrium state in failure may be affected. Secondly, the strain hardening of the alloy directly affects the distribution of the bending moment along the T-stub flanges, after emergence of the plastic hinges. For these two reasons, in order to take into account the effects of the strain hardening and the ductility reduction of aluminum alloy, it is necessary to amend plastic loads properly when the conventional approach is adopted for analysis of the plastic collapse of aluminum structures (Mandara [25], Matteis [26]). The third factor for considering additional failure mechanisms is the reduced axial stiffness of the aluminum alloy bolts. It obviously influences the deformation path of the T-stub. In addition, the deformation capacity of bolts may be limited by the premature failure of the flanges.

The failure mode type-2 has been subdivided into three different situations (Matteis [24]), depending on the predominant element of the collapse(Figure 3). Compared with the failure mechanism type-1, the plastic deformation has also taken place in bolts and the plastic deformation in flanges is larger than that in bolts. The distribution of bending moments in flanges and the formula of the ultimate load-bearing capacity of type-2a are the same as those of type-1. The mechanism type-2b can be treated as a special case of type-2a, where the plastic deformation of both flanges and bolts reaches to limit simultaneously.

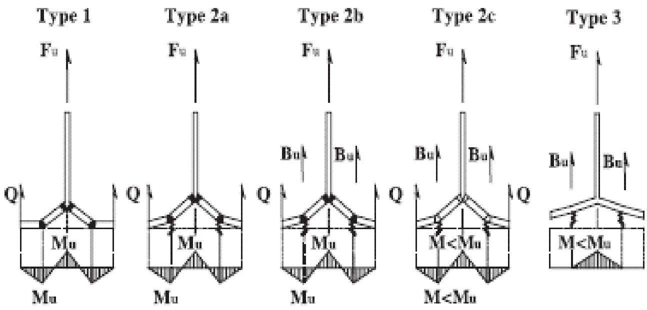

Figure 3: Failure mechanisms for aluminum T-stubs.

The failure mechanism type-2 cannot be so clearly defined in aluminum alloy joints as in steel joints, owning to the stronger influence of interaction between bolts and flanges, as well as the effect of the material strain hardening. The numerical analysis (Matteis [24]) shows that the failure mechanisms of a joint can be predicted correctly only when the effect of material strain hardening is neglected. For aluminum structures, it may be impossible, especially when the strength of bolts and flanges is comparable. A useful conclusion is obtained that the mechanism type-1 seems to be favorable for practical application of aluminum joints since the highest resistance of a joint can be reached if the geometry and size are determinate.

3.3. Load-bearing capacity of aluminum T-stubs

In EC9, the minimum load-bearing capacity of four failure modes should be taken as the tension resistance of a T-stub. The mechanism type-1 and type-3 in EC9, as shown in Figure 4, are the same as in Figure 3. The mechanism type-2 is futher divided into two different modes, type-2a and type-2b, in EC9. For mechanism type-2a, the plastic hinges develop at the junction of flange and web firstly, and the bolts reach the ultimate elastic strength simultaneously. Whereas for mechanism type-2b, ultimate strength first reaches in bolts, but no plastic hinge has formed in flange yet. And the plastic deformation develops in the junction of flange and web and the sections of bolt holes.

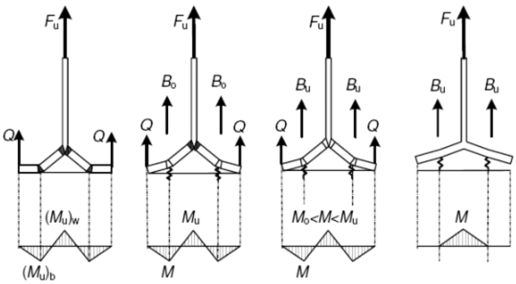

Figure 4: Failure mechanisms of an aluminum T-stub according to EC9

The tension resistance of a T-stub corresponding to each failure mode in EC9 should be calculated as follows.

Mode-1: $$F_u = \frac{2(M_u)_w + 2(M_u)_b}{m} \quad (9)$$

Mode-2a: $$F_u = \frac{2M_u + n\sum B_0}{m+n} \quad (10)$$

Mode-2b: $$F_u = \frac{2M_0 + n\sum B_u}{m+n}$$
(11)

Mode-3: $$F_u = \sum B_u \quad (12)$$

Where M_0 and M_u are moments related to material characteristic, total thickness of the joint, effective width of flanges, production process (welding or rolling) of connector (Matteis [27]). In the case of mechanism type-2b, the ultrimate elastic bending moment is adopted in calculation of F_u conservatively.

The influence factors of the prying force in an aluminum T-stub with rigid backplanes were analyzed (Zhang [42] and [43]). A preliminary method was proposed (Zhang [44]) for design of aluminum T-stubs. However, it cannot be adopted directly in specifications without experimental verification and indistinction of failure modes. Tension tests (Li [18]) of T-stub connections have proved that it is accurate and safe to adopt the formulas of EC3 in design of aluminum alloy joints. And some conclusions (Li [18], Engineering [12], Shanghai [38]) have been adopted in the first edition of the code for design of aluminum structures in China (National [29]).

4. Combination of shear and tension

A bolt subjected to combination of shear and tension should be, in addition, checked in EC3 as follows

$$\frac{F_{v,Ed}}{F_{v,Rd}} + \frac{F_{t,Ed}}{1.4F_{t,Rd}} \leq 1.0 \tag{13}$$

Where $F_{v,Rd}$ and $F_{t,Rd}$ are design shear resistance and design tension resistance of the bolt, respectively. $F_{v,Ed}$ and $F_{t,Ed}$ are design shear and design tension respectively.

A similar methord is adopted in design of a bolt subjected to combination of shear and tension in China design code GB50017.

$$\sqrt{\left(\frac{N_v}{N_v^b}\right)^2 + \left(\frac{N_t}{N_t^b}\right)^2} \leq 1.0 \quad \text{and} \quad N_v \leq N_c^b \tag{14}$$

Where N_c^b is the design compressing strength of a bolt.

The design methods of bolted joints in steel structures under combination of shear and tension in EC3 are adopted in aluminum alloy joints. Numerical analysis (Shi [36]) about T-stubs suffering both shear and tension shows that it is not safe to adopt the formulas of GB50017 in design of bolted joints in aluminum alloy structures. And safer design formulas are recommended as follows.

$$\sqrt{\left(\frac{N_v}{N_v^b}\right)^2 + \left(\frac{N_t}{N_t^b}\right)^2} \leq 0.8 \quad \text{and} \quad N_v \leq N_c^b \tag{15}$$

This proposal not only meets the requirement of safety but also is convenient for design.

5. Conclusions

The researches about aluminum alloy structures are quite advanced in Europe. Taking account of the different properties of aluminum alloy from steel, the design codes for steel structures are improved for design of aluminum structures now. Howecer, there is no applicable design specifications for aluminum alloy structures in China so far. In a local standard of Shanghai, the same design methods as GB50017 are adopted for design of aluminum bolted joints without considering the differences between steel and aluminum.

Numerical computation is the main method for analysis of aluminum joints in China nowadays. Therefore, the resistance indeterminacy of aluminum structures cannot be defined for lack of adequate test data, and the resistance partial coefficient of aluminum alloy members fails to be determined by reliability analysis. The researches about the fatigue behavior of aluminum bolted joints are confined to the fields of aerospace and metallurgy, and do not extend into the building structures yet.

The researches on aluminum bolted connections improve steadily in China at present. A wide researches about application of aluminum structures have been conducted in the R&D project of Shanghai. The test database of aluminum bolted connections will be built and the design system will be established based on reliability.

References

[1] AISC, *Load and Resistance Factor Design Specification for Structural Steel Buildings.* American Institute of Steel Construction, Inc ,2000.

[2] Aluminum Association, *Aluminum Design Manual,* Washington, DC, U.S.A. 1994.

[3] Atzori B., Lazzarin P. and Tovo R., *Proceedings of the Sixth International Conference on Aluminum Weldments,* Cleveland, OH, U.S.A., 1995.

[4] Atzori B., Lazzarin P. and Quaresimin M., A re-analysis on fatigue data of aluminum alloy bolted joints. *International Journal of Fatigue.* 1997;**19(7)**; 579-588.

[5] Berstad T., Hopperstad OS. and Langseth M., Elasto-visco-plastic constitutive models in the explicit finite element code LS-DYNA3D. *in Conf. Livermore Software Corporation,* Livermore, CA,1994, *20,*

[6] BS 8118-91, *Structural use of aluminum. Part 1: Code of Practice for Design, Part 2: Specification for Materials, Workmanship and Protection.* London, U.K., 1991.

[7] Cheng Ming., Shi Yong-jiu. and Wang Yuan-qing., Connection of aluminum members and design method. *Building Science.* 2006; **22(3)**; 85-88.

[8] Bulson P S., *Aluminum Structural Analysis-Recent European Advances. Chapter 6: Joints with Mechanical Fasteners.* London and New York, 1992.

[9] Eurocode3, *Design of Steel Structures. Part 1-8: Design of Joints.* CEN/TC250/SC3, 1993.

[10] Eurocode9, *Design of Aluminum Structures. Part 1-1: General Structural Rules.* CEN/TC 250/SC9-PT9, 1997.

[11] ECCS, *European Recommendations for Aluminum Alloy Structures*. (1st ed.), 1978.

[12] Engineering Construction Standard, *Aluminum Cancelled Structures Technical Regulation,* ShangHai, China.

[13] Federico M. Mazzolani., *Aluminum alloy structures*. Boston, Pitman, 1985.

[14] Guo Xiao-nong, Shen Zu-yan, Li Yuan-qi, Su Ci, Qiu Zhen-ge, and Yao Nian-liang, Stress-strain relationship and physical-mechanical properties of domestic structural aluminum alloy. *Journal of Building Structures.* 2007; **28(6)**; 110-117.

[15] Kissell, J. Randolph F, Robert L., *Aluminum Structures: A Guide to Their Specifications and Design.* New York John Wiley & Sons, Inc. (US), 2002,251-289.

[16] Kulak G L. and Fisher J W., *Guide to Design Criteria for Bolted and Riveted Joints.* (2nd ed.), New York, John Wiley & Sons, 1987.

[17] Kato B. and McGuire W., Analysis of T-stub flange to column connection. *J Struct Div,* 1973; **90**; 865-88.

[18] Li Jing-bin, Zhang Qi-lin and Ding Jie-min, Study on load-Bearing capacity of aluminum bolted joints. *Progress in Steel Building Structures.* 2008; **10(1)**; 15-21.

[19] Lazzarin P., Milani V. and Quaresimin M., Scatter bands summarizing the fatigue strength of aluminum alloy bolted joints. *International Journal of Fatigue.* 1997; **19(5)**; 401-407.

[20] LABEIN Report 90.082-3-ME/9, *Final test results of aluminum connections-Series A*. (EUREKA Project 269-DASFA13), Bilbao, Spain, 1993.

[21] LABEIN Report 94/253ME-4, *Average and design lines from test data groups and combinations. (Revision 1)*, (EUREKA Project 269-FAL), Bilbao, Spain, 1995.

[22] Lazzarin P. and Quaresimin M., *Analysis of fatigue behavior of bolted joints in aluminum alloys.* Internal Report CM 95.3, Department of Mechanical Engineering, University of Padova, Padova, Italy, Feburary,1995.

[23] Lazzarin P., Milani V. and Quaresimin M., Scatter bands summarizing the fatigue strength of aluminum alloy bolted joints. *International Journal of Fatigue.* 1997; **19(5)**; 401-407.

[24] Matteis D G., Mandara A. and Mazzolani F M., T-stub aluminum joints: influence of behavioral parameters. *Computers and Structures.* 2000; **78(2)**; 311-327.

[25] Mandara A. and Mazzolani F M., Behavioral aspects and ductility demand of aluminum alloy structures, *in Proc Third Int Conf On Steel and Aluminum Structures,* ICSAS '95, Istanbul, 1995.

[26] Matteis D G., Mandara A. and Mazzolani F M., Remarks on the use of EC3-Annex J for the prediction of aluminum joint behavior. *In Proc of Sixth Int Coll on Stability and Ductility of Steel Structures (SDSS'99),* Dubina D. and Ivanyi M., Editions. Timisoara, Romania., 1999, 229-40.

[27] Matteis D G. and Mandara A., Effect of technological factorson the behavior of T-stub aluminum joints. *Proc of the European Conference on Computational Mechanics.* Munich, Germany, 1999.

[28] National Standard of China, *Code for design of steel structures,* GB 50017-2003.

[29] National Standard of China, *Code for design of aluminum structures,* GB 50429-2003.

[30] Nair R.S., Birkemoe P C. and Birkemoe W H., High strength bolts subject to tension and prying*, Journal of Structural Division,* 1974; **100(2)**; 351-372.

[31] Ramberg W. and Osgood W R., *Description of Stress-stain Curves by Three Parameters.* Washington DC, NACA TN-902, 1943.

[32] Ramirez J L., Aluminum Structure Connections: Conventional Slip Factors in Friction Grip Joints. *In R. Narayanan. Aluminum structures: advances, design and construction.* 1987, 115-125.

[33] Shen Zu-yan, Guo Xiao-nong, Li Yuan-qi, State-of-the-arts of research on aluminum alloy structures. *Journal of Building Structures.* 2007; **28(6)**; 100-109.

[34] Shi Yong-jiu, Zhang Gui-xiang, Wang Yuan-qing, Shear resistance of bolted connection in aluminum structures. *Progress in Steel Building Structures.* 2008; **10(1)**; 1-7.

[35] SteinHardt O., Aluminum constructions in civil engineering. *Aluminum*, 1971; **47**; 131-139.

[36] Shi Yong-jiu, Zhang Gui-xiang, Wang Yuan-qing, Load carrying properties of bolted connection in aluminum alloy which carried both tensile and shear force. *Journal of Yantai University.* 2007; **20(4)**; 299-303.

[37] Sharp M L., *Behavior and Design of Aluminum Structures.* New York, McGraw-Hill, 1993.

[38] Shanghai Institute of Architectural Design and Research Co. Ltd., Tongji University, Shanghai Gaoxin Aluminum Engineering Co. Ltd., *Research Report on Aluminum Cancelled Structure Complete Set Technology R&D,* ShangHai, China, 2006.

[39] UNI 8634-85, *Light Alloy Structures, Specifications for Design and Workmanship*. UNI, Milan, Italy, 1985.

[40] Wang Yan, Analysis on prying force of semi-rigid beam-column connections of steel structure. *Industrial Construction,* 2004; **34 (7)**; 70-72.

[41] Zhang Gui-xiang, Shi Yong-jiu, Wang Yuan-qing, Analysis and design method of bearing strength of bolted connection in aluminum alloy. *Journal of Hebei Institute of Architectural Science and Technology,* 2006; **23(4)**; 19-22.

[42] Zhang Gui-xiang, Shi Yong-jiu, Wang Yuan-qing, Finite element analysis of parameters related to prying force of T-stub connection in aluminum alloy. *Engineering Journal of Wuhan University,* 2007; **40(1)**; 91-95.

[43] Zhang Gui-xiang, Shi Yong-jiu, Wang Yuan-qing, Cheng Ming, Analysis and design of bearing strength of bolted connection in aluminum alloy. *Journal of Guilin University of Technology,* 2006; **26(4)**; 501-505.

[44] Zhang Gui-xiang, Shi Yong-jiu, Wang Yuan-qing. Design method for aluminum alloy T-stub tensile connection considering prying action. *Journal of Shandong Jianzhu University,* 2006; **21(6)**; 483-488.