Evaluation of the Bolt Axial Force in High Strength Bolted Joints by Using Strain Gauges

Chao PAN *, Takashi YAMAGUCHI ** and Yasuo SUZUKI ***

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Synopsis

In Japan, high strength bolted joints frequently used in steel bridge structures, because high strength bolted joints are easy to joint members than welding from the view point of construction and qualification. On the other hand, performance based design method for bridge structures is being established in Japan to be possible to consider various limit states. Therefore, the high strength bolted connections must be considered various limit states, such as slip state, bearing state, and tearing state. It is important point to understand such behaviors to know the change of bolt axial force at the various limit states. The objective of this study is to collect information of the change of bolt axial force experimentally by using strain gauges in which fastened the connected members until the ultimate limit state and to find the preferable measuring method of it by strain gauges.

KEYWORDS: slip state , bearing state, tearing state ,axial force, strain gauges

1.Introduction

In this study, two methods are taken into consideration. One is the method to glue two strain gauges on the bolt shank and the other is the method to glue the strain gauges on the surface of the bolt head as shown in Fig. 1 respectively. The former method is needed to make two small holes for wires of strain gauges and it is wondering that they might be cut after slip state for friction type connection. The latter method does not need to make holes and less possibility of cutting wires. In order to understand the characteristics of two methods preciously, the experiment and finite element analysis (FEA) has been carried out and discussed about influenced factors, such as the position of glued strain gauges, the measured length of the strain gauge.

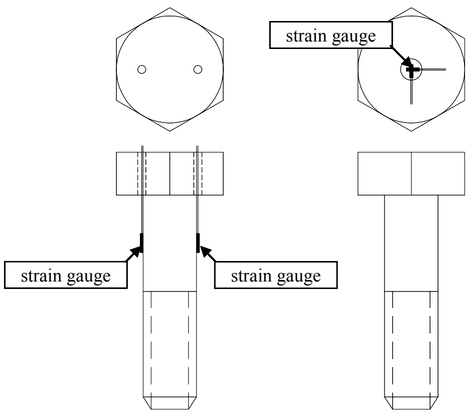


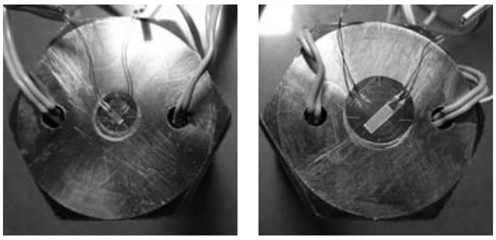
Fig.1 Strain gauges on bolt shank and on head

2. Calibration experiment

Calibration experiment[1)] is conducted to find relationships between load (bolt axial force) and strain (form strain gauge). In experiment, 22mm diameter bolts which grade is 1000MPa are used. Both of the head strain and shank strain were measured by 90° double-element cross strain gauge and single element strain gauge[2)].

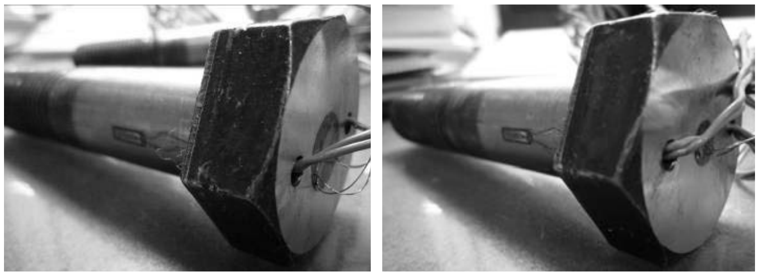
* Student, Doctor Course of Dept. of Civil Engineering, Osaka City University
** Professor, Dept. of Civil Engineering, Osaka City University
*** Associate Professor, Dept. of Civil Engineering, Utsunomiya University

In Fig.2, single element gauge which gage length is 5mm are glued to bolt shank for measuring shank strain. 90^o double-element cross strain gauges which gauge length is 2mm/5mm, are used for measuring head strain. Two types of specimens are named, K2 (90^o double-element cross strain gauge length 2mm) and K5 (90^o double-element cross strain gauge length 2mm) respectively as shown in Fig.3.



(a) length 2mm (b) length 5mm

Fig.2 90^o double-element cross strain gauge



(a) specimen K2 (b) specimen K5

Fig.3 Specimen K2 and K5

Specimens are loaded by jigs as show in Fig.4. Each K2 and K5, had executed three times of each specimens. The results are shown in Fig.5 and Fig.6 . Fig.5 shows a results of load versus head strain curves and Fig.6 shows results of load versus shank strain.

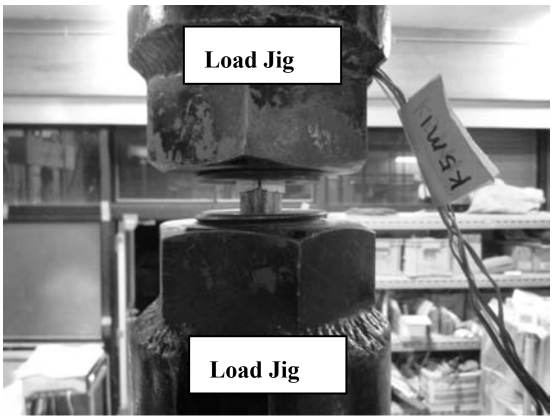


Fig.4 Calibration experiment

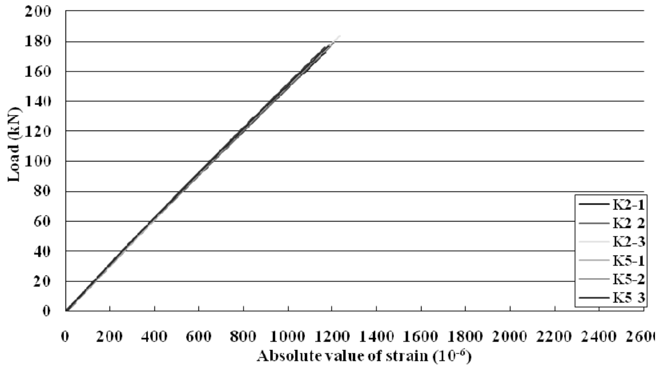


Fig.5 Load versus head strain

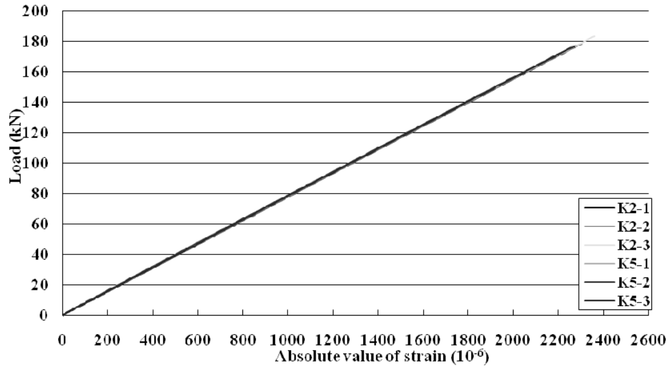


Fig.6 Load versus shank strain

Each of load versus strain relationships (which is measured by head strain gauge and shank strain gauge) is alignment as show in Fig. 5 and Fig. 6. Variation of gradient of the curve from head strain is larger than that from shank strain . The results of calibration experiment also show in Table.1 for discussion.

Table.1 Statistics of K2 and K5

	K2		K5	
	Load/ Shank strain	Load/ Head strain	Load/ Shank strain	Load/ Head strain
Average value	77.56	147.29	77.65	149.33
Standard deviation	0.18	1.07	0.14	0.98
Coefficient of variation	0.0024	0.0073	0.0018	0.0066

In Table.1, the accuracy of the measurement results of strain by shank and head strain gauge are compared. In the results of specimen K2, the standard deviation of load/shank strain is 80% off than the standard deviation of load/head strain, the coefficient of variation is 65% off. In the results of specimen K5, the standard deviation of load/shank strain is 85% off than the standard deviation of load/head strain, the coefficient of variation is 70% off. By the results, the accuracy of the measurement by using shank strain is better than that by using head strain. Comparing the length of head strain gauge for accuracy of the measurement, 5mm length (K5) is better than 2mm length (K2).

3.Finite element analysis (FEA)

Finite element analysis (FEA) is conducted to simulate bolt that is fastened in bolt hole. Two case were set, bolt is fastened on bolt hole axial or off bolt hole axial. FEA software ABAQUS[3)] is used in this study. In the case of bolt off bolt hole axial, bolt axial offside bolt hole axial 2mm are set. FEA model is show in Fig.7.

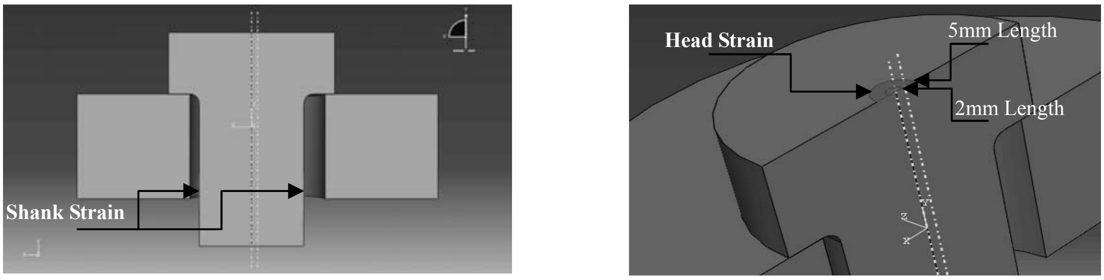


Fig.7　FEA model

The FEA result and experimental result are shown with bolt axial force versus shank strain in Fig.8. Bolt axial force versus head strain (2mm strain gauge length) show in Fig.9. Bolt axial force versus head strain (5mm strain gauge length) show in Fig.10.

In Fig.8, both FEA results and experimental results are on a same line. It means that accuracy of the measurement by shank strain got a better quality. Other results show in Fig.9 and Fig.10.

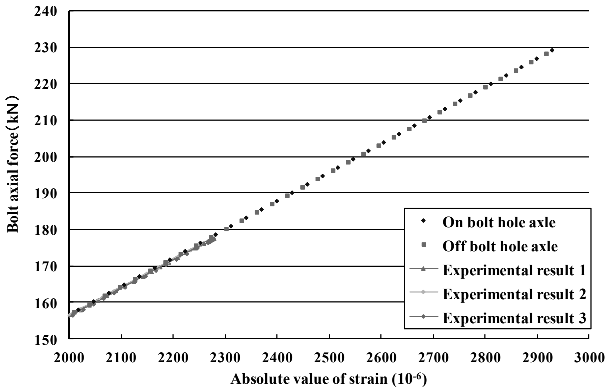


Fig.8　Bolt axial force versus shank strain

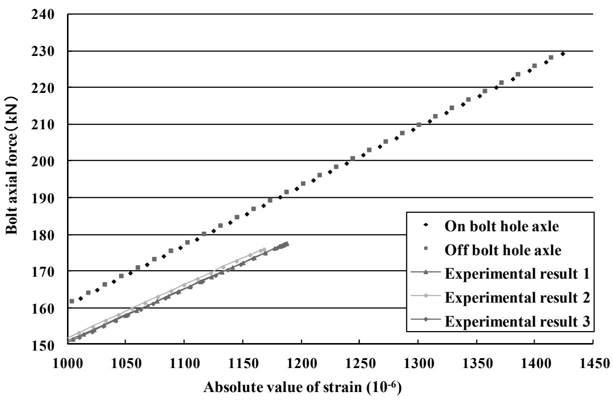


Fig.9　Bolt axial force versus head strain (2mm)

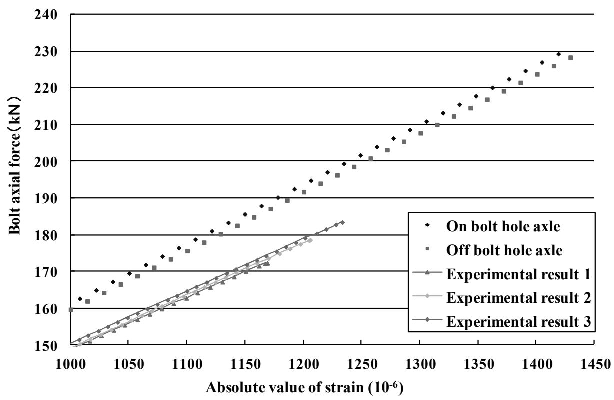


Fig.10　Bolt axial force versus head strain (5mm)

Table.2 Statistics of head strain and shank strain

	Head (gauge length 2mm)		Head (gauge length 5mm)	
	on bolt hole axial	off bolt hole axial	on bolt hole axial	off bolt hole axial
Load/Head strain	161.52	159.72	161.02	161.51
Average value	160.62		161.26	
Standard deviation	0.90		0.24	
Coefficient of variation	0.0056		0.0015	
	Shank			
	on bolt hole axial	off bolt hole axial		
Load/Shank strain	78.35	78.31		
Average value	78.33			
Standard deviation	0.02			
Coefficient of variation	0.0003			

Table.2 show statistics of head strain and shank strain by FEA. In Table.2, the standard deviation value of shank strain which is 95% off than head strain, the coefficient of variation of shank strain which is 90% off than head strain. By the result, using shank strain can get a very good accuracy of the measurement. However, using head strain can't get accuracy of the measurement as good as shank strain, but between gauge length 2mm and gauge length 5mm, gauge length 5mm get a better accuracy of the measurement than gauge length 2mm.

4. Fasten experiment

Actually, bolt is fastened by a torque wrench[4)]. In this experiment, use a torque wrench to fasten each specimen, that which can just fasten bolt by need torque value. Same bolts (22mm diameter 1000MPa grade high strength bolt) are used for the specimen for K2 and K5. Three specimens are used to get shank strain by 5mm length single element gauge, named shank strain 1,2,3. The other three specimens are used to get head strain by 5mm length 90^{o} double-element cross strain gauge, named head strain 1,2,3. Use load/strain relation to convert that both shank strain and head strain to bolt axial force. Plot equivalent bolt axial force versus torque in Fig.11. Input torque values are set from 100 N · m to 800N · m, each per 100 N · m are raised.

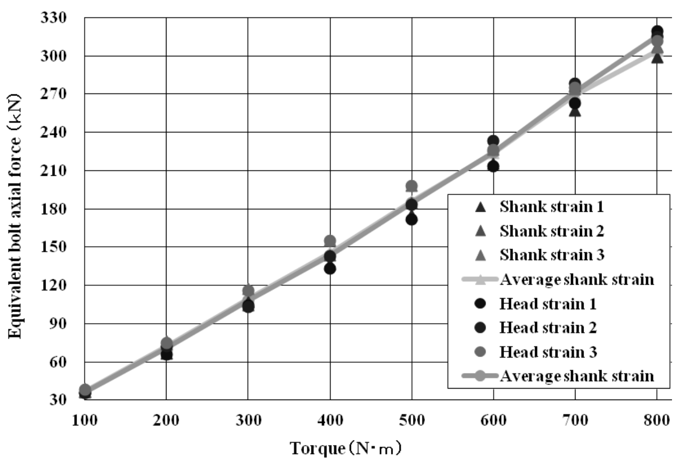


Fig.11. Bolt axial force versus torque

In Fig.11, under 600 N · m torque value, both shank strain and head strain average value nearly on a same line . Over 600 N · m torque value, the equivalent bolt axial force by measuring from head strain gauge, is larger than the equivalent bolt axial force by measuring from shank strain gauge. At 800 N · m torque value, the equivalent bolt axial force of head strain is larger than the equivalent bolt axial force of shank strain. Therefore, both the two way under torque value 600 N · m, can put out a nice equivalent bolt axial force.

5. Conclusion

The main results of the present study are summarized as followings:

1) The method of measuring bolt shank strain by 5mm length single element gauge, it can get higher precision to convert bolt axial force than measuring bolt head strain by 90^o double-element cross strain gauge. Even if bolt is fastened off bolt hole axial, it also can get high precision.
2) In the method of measuring bolt head strain by 90^o double-element cross strain gauge, the gauge length of 5mm is recommended, because it can get higher precision than gauge length 2mm.
3) On bolt bearing state, the method of measuring bolt head strain by 5mm length 90^o double-element cross strain gauge is recommended, because it don't about cutting wires.

6. References

1) Recommendations on Design, Construction and Maintenance for Friction Type of High Strength Bolted Connections, *Subcommittee on Design of Friction Type of High Strength Bolted Connections Committee on Steel Structures Japan Society of Civil Engineers, December 2006* .
2) Specifications for Highway Bridges, *Japan Road Association, 2002*.
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