DEFORMATION CAPACITY OF LARGE DIAMETER HIGH STRENGTH BOLTS WITH WAISTED SHANK SUBJECTED TO AXIAL TENSILE FORCE

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Synopsis

In case of applying axial tensile force to a high strength bolt, in general, stress is concentrated at the bottom of the threaded portion. As a result, its failure mode of it is brittle due to lack of ductility. In this study, the mechanical behavior of high strength bolts with waisted shank subjected to axial tensile force has been numerically analyzed by FE analysis considering both material and boundary non-linearity. Based on these numerical results, an optimal diameter of the waisted shank of the large diameter bolts is discussed focused on their energy absorption capacity. It is concluded from the FE analysis that the optimal diameter of the waisted shank is a little smaller than the effective diameter of the bolts specified in Japanese Industrial Standards, JIS.

KEYWORDS: large diameter high strength bolt with waisted shank, energy absorption capacity

1. Introduction

By recent years, high strength bolts with large diameter which is more than 30mm are expected to be used for bolted joints because of decreasing the number of the bolts for both friction type and tension type from the viewpoint of reduction of fabrication cost. In particular, the large diameter high strength bolt is very effective for tension type joints. Considering improving the strength of bolted tensile joints, multiple bolt arrangements like friction type joints with high deformability bolt at the tee web side as shown in **Fig.1** will be needed. But in general, the failure mode of the bolts is brittle due to stress concentration at the bottom of the threaded portion of the bolts under axial tensile force. Therefore, improvement of deformation capacity is required in order to make the large diameter high strength bolt effective for using in the tension type joints in case of tension type joints. For example, it has been reported that the high strength bolt with waisted shank as shown in **Fig.2** can have high deformability.

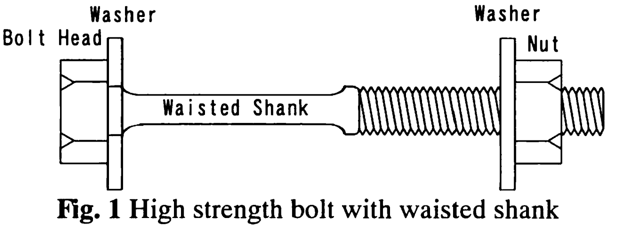

Fig. 1 High strength bolt with waisted shank

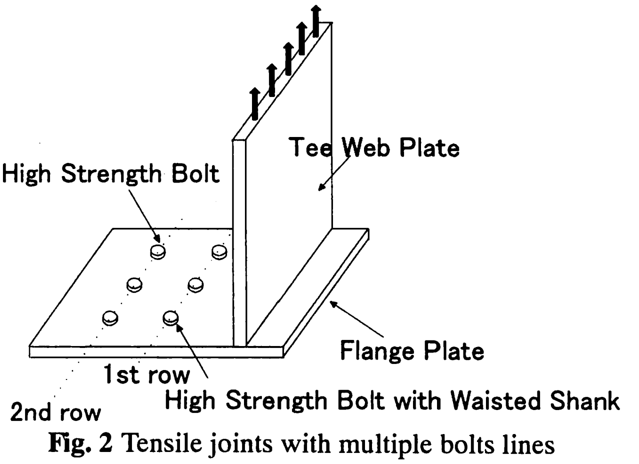

Fig. 2 Tensile joints with multiple bolts lines

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In this study, M30 bolt whose diameter of the shank is 30mm are dealt with as the large diameter high strength bolt. And in order to investigate the optimal diameter of the waisted shank for improving the ductility, FE analysis has been carried out considering both material and geometrical non-linearity subjected to axial tensile force.

2. ANALYTICAL MODEL

In order to obtain the relation of the bolts between load and elongation, FE analysis was carried out at first. And then, energy absorption capacity is calculated based on the analytical results. In the analysis, the diameter of the shank, length of the shank, and nut position are varied. All of the cases are listed in **Table 1**. The overview of the analytical model is shown in **Fig. 3**. Shank diameter is varied from 30mm to 20mm. The length of shank, L is set to be 87.5, 125.5 and 159.5mm because of investigating influence of the clamp length.

As for the analytical case, the first character of each analytical case denotes, the length of shank, namely S is L=87.5 mm, M is L=125.5 mm and L is L=159.5 mm respectively. The number following first character shows the diameter of shank. And the last character denotes the position of the nut. That is, s means that the nut is located at the 5th thread from the incomplete thread section. And l means that the nut is located at the 9th thread.

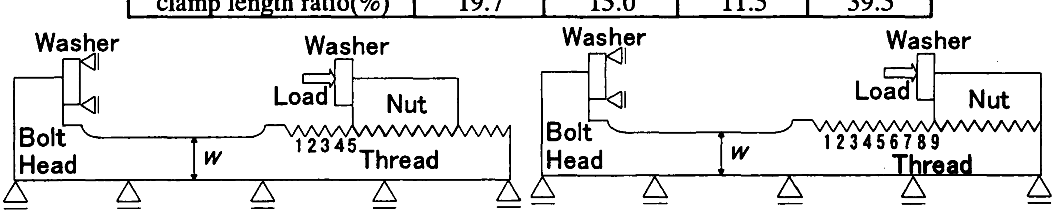
Overview of analytical model used in this analysis is shown in **Fig. 3**. In fact, the threaded section is spiral shape, however in this analysis, as shown in **Fig. 3** the model is assumed to be axisymmetric.

Basically, isoparametric 4 nods or 3 nods elements are used. But, thread and incomplete thread section are divided finely by higher-mode isoparametric 6 nods or 8 nods elements. Washers are modeled as the rigid body. Maximum number of the nodes is 8536 among of all cases.

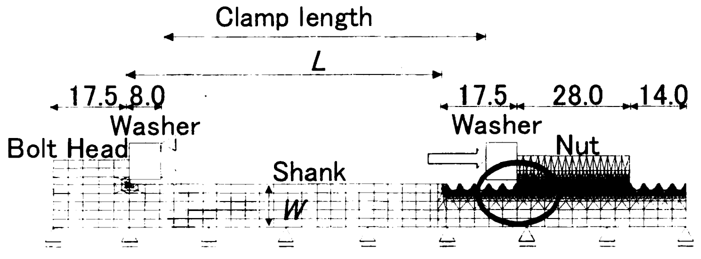
The surface between the nut thread and the bolt thread, between the washer and the nut, and between the washer and the bolt head are assumed to be a separatable surface considering slip. Contact elements are located into these surfaces. As a result, boundary non-linearity is considered in this analysis.

Table 1 List of anarytical cases

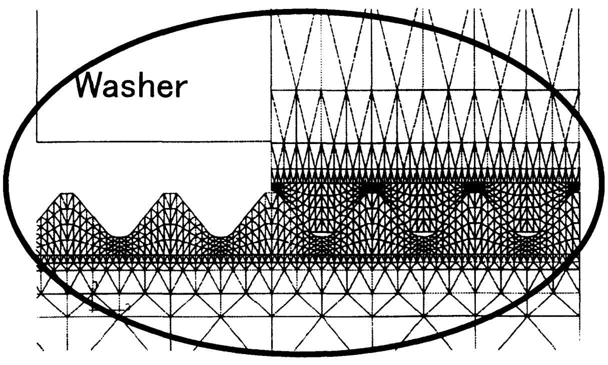
type	S-s type	M-s type	L-s type	S-l type
cases	S-30.0-s	M-30.0-s	L-30.0-s	S-30.0-l
	S-27.9-s	M-27.9-s	L-27.6-s	S-27.4-l
	S-27.6-s	M-27.6-s	L-27.5-s	S-27.2-l
	S-27.5-s	M-27.5-s	L-27.4-s	S-27.1-l
	S-27.4-s	M-27.4-s	L-27.2-s	S-27.0-l
	S-27.2-s	M-27.2-s	L-26.8-s	S-26.8-l
	S-26.8-s	M-26.8-s	L-25.7-s	S-24.0-l
	S-26.0-s	M-25.0-s	L-24.0-s	S-20.0-l
	S-25.7-s	M-23.0-s	L-20.0-s	
	S-25.0-s	M-20.0-s		
	S-24.0-s			
	S-23.0-s			
	S-22.0-s			
	S-21.0-s			
	S-20.0-s			
clamp length(mm)	89	127	161	103
clamp length ratio(%)	19.7	15.0	11.5	39.5



(a) s type (b) l type



(a) Overall view (unit:mm)



(b) Nut and thread section

Fig.3 Overview of the analytical model and element divisions

Table-2 Material properties of high strength bolt

Young's modulus(N/mm^2)	Poisson's ratio	yield point(N/mm^2)	ultimate stress(N/mm^2)	elongation(%)
206,000	0.3	900	1000	14

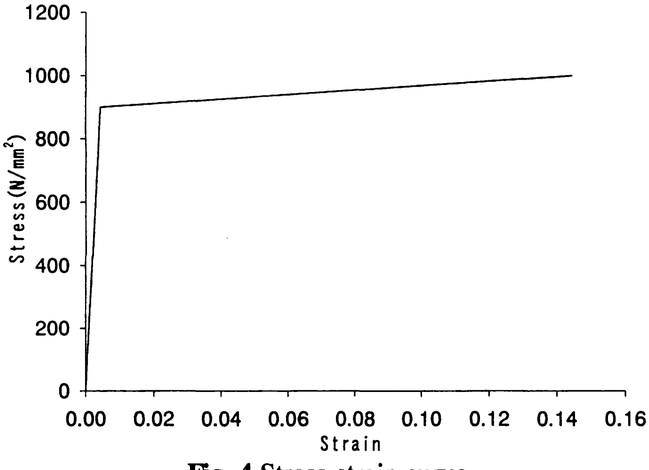


Fig. 4 Stress-strain curve

The material property used in the analysis is tabulated in **Table.2.** These values are determined based on the JIS. Stress-strain curve used in the analysis are shown in **Fig. 4.**

Elasto-plastic constitutive rule used is isotropic work-hardening and associated flow rule based on the Von Mises yielding function.

The ultimate state defined in this analysis is the state that stress of some elements reaches to 1000N/mm^2.

3. Results and discussions

3.1 Maximum strength and ultimate failure mode

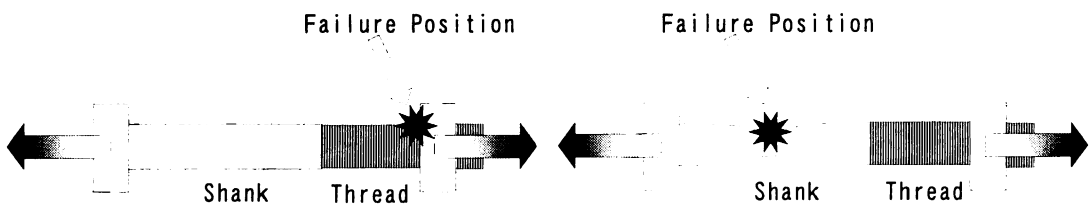
The maximum load of all cases and ultimate failure mode are listed in **Table.3.**

The ultimate failure mode changes at 27.4 mm of diameter for S-s, M-s, L-s types. The case with the diameter of the shank is larger than 27.4mm is failed at the threaded section. On the other hand, the case with the diameter of the shank is smaller than 27.4mm is failed at the shank. Therefore in case of practical use, ultimate failure mode seems not to be influence by the shank length. But in case of S-l, the failure mode changes at 27.0mm. It will be found that the length of threaded section influences a little on the failure mode. These diameters are almost same as the effective diameter specified in JIS.

Table-3 Maximum load and ultimate failure mode

	W(mm)	30	27.85	27.6	27.5	27.4	27.2	27.1	27	26.8	26	25.7	25	24	23	22	21	20
S-s	maximum load(kN)	537.6	534.1	533	532.3	529.5	521.9			506.5	476.8	466.1	440.8	406.1	373.0	341.2	310.8	281.9
	ultimate strain	0.009	0.009	0.009	0.01	0.057	0.055			0.053	0.052	0.051	0.05	0.05	0.048	0.047	0.046	0.044
	ultimate mechanism	T	T	T	T	S	S			S	S	S	S	S	S	S	S	S
M-s	maximum load(kN)	537.7	534	533	532.3	529	521.4			506.1			440.4		372.8			281.8
	ultimate strain	0.007	0.008	0.008	0.008	0.052	0.051			0.05			0.047		0.046			0.041
	ultimate mechanism	T	T	T	T	S	S			S			S		S			S
L-s	maximum load(kN)	537.7		533	532.3	529	521.4			506.1		465.7		405.9				281.8
	ultimate strain	0.006		0.007	0.007	0.04	0.041			0.039		0.038		0.034				0.031
	ultimate mechanism	T		T	T	S	S			S		S		S				S
S-l	maximum load(kN)	517.1				516.6	516.5	516.5	514.3	506.4				406.2				281.9
	ultimate strain	0.014				0.014	0.014	0.014	0.05	0.049				0.044				0.04
	ultimate mechanism	T				T	T	T	S	S				S				S

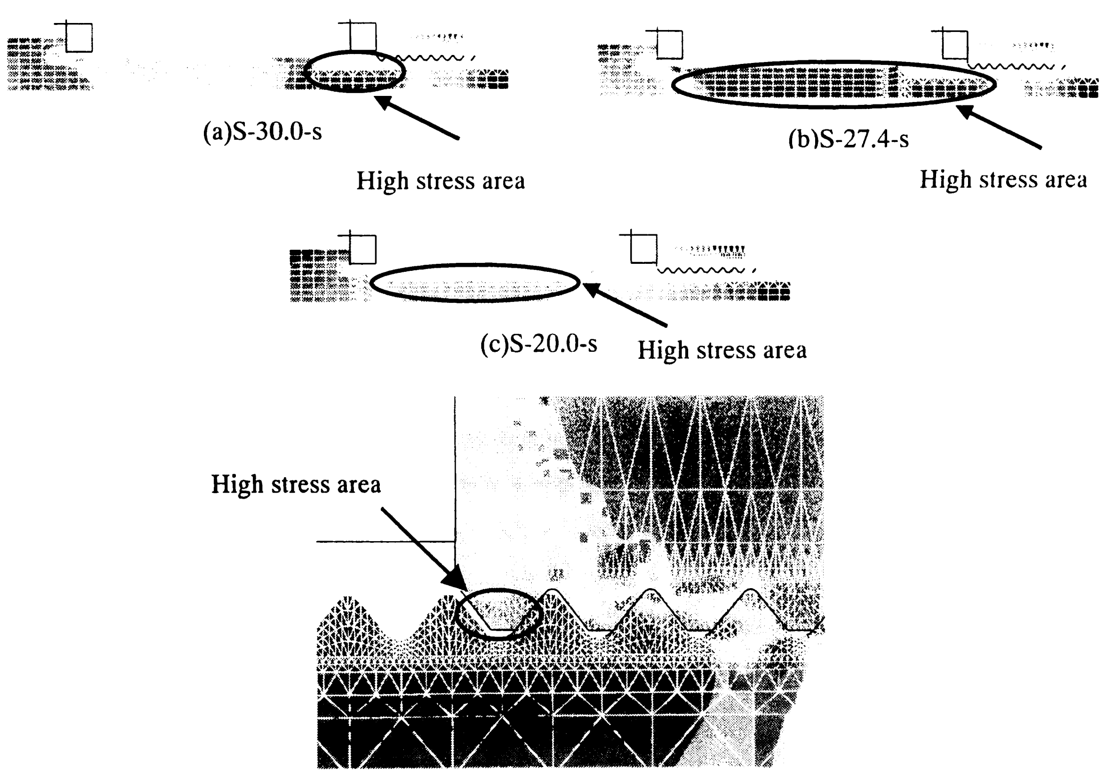
S: It is a case to the ultimate condition in shank. T: It is a case to the ultimate condition in thread.



(a) T (ultimate state at the thread) (b) S (ultimate state at the shank)

3.2 Stress distribution

Typical stress distribution of some analytical cases when the load is nearly ultimate strength is shown in **Fig. 5**. In this figure, high stress area is surrounded by an ellipse.



(d)S-30.0-s(detailed figure at the nut and the thread section)

Fig. 5 Stress distribution at the ultimate state

In case of S-30.0-s which diameter of the bolt is the nominal diameter, the high stress occurs at the 1st thread bottom of the nut and the threaded section. On the other hand, shank is in elastic. In case of S-27.4-s which diameter is almost same as the critical diameter, high stress occurs at both the thread and the shank section. And it is found that the plastic regions spread to both thread and shank regions. However, in case of S-20.0-s which diameter is smaller than the critical diameter, high stress occurs at the shank and also plastic deformation occurs only at shank.

3.3 Energy absorption capacity and optimal diameter

In order to investigate an optimal diameter of high strength bolt with waisted shank focused on high deformability. Energy absorption capacity of the bolts with waisted shank until the ultimate state is discussed. In this study, The area under the stress-strain curves is calculated by the trapezoid formula. Obtained results are shown in **Fig. 6**.

From this figure, energy absorption capacity shows the highest value in case of W=27.4 mm in S-s, M-s and L-s types.

In the case with the diameter which is larger than 27.4mm, energy absorption capacity decreases significantly. This means that energy absorption capacity of the normal bolt is not high. Because threaded section reaches to ultimate state immediately when even though the stress at the shank is in elastic. On the other hand, as the diameter becomes smaller than diameter of the shank, 27.4mm, absorption capacity is high by about 10 times compared with the normal bolt. And the energy absorption capacity becomes low gradually. It is caused by the decrease of sectional area of shank mainly. And as for S-l, energy absorption capacity becomes the highest when the diameter is W=27.0mm. From the viewpoint of practical production of the bolts, it is considered that there is a little difference between this type and S-s, M-s and L-s. It is considered that which shows there is not difference.

The diameter specified in British standard is about 10 % smaller than the optimal diameter. It is though that high strength bolt with waisted shank specified in the British standard put emphasis on the securing of deformation capacity.

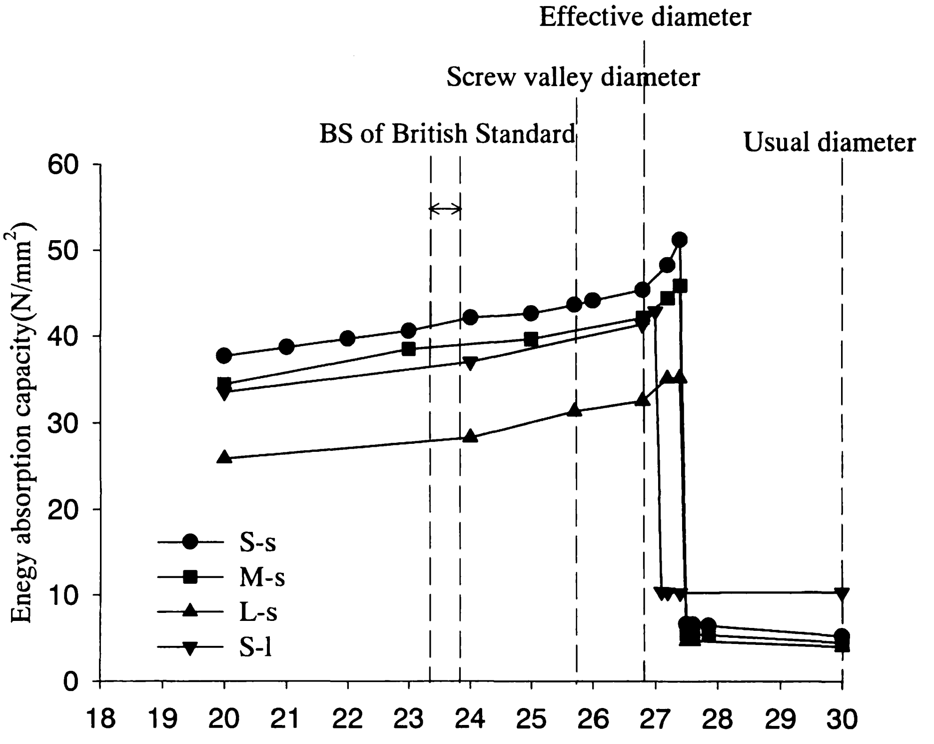


Fig. 6 Energy absorption capacity

4. Conclusion

The following conclusions may be drawn:

(1) It thinks that concentration of stress occurs to thread(screw bottom) at usual bolt and that it shows brittleness. At this time, shank is totally in elastic condition. On the other hand, at high strength bolt with waisted shank, plastic deformation capacity in shank excels and it shows ductility.

(2) As for energy absorption capacity, diameter of shank becomes maximum in case of W=27.0～27.4 mm. When the rate with length of thread changes, energy absorption capacity changes a little. But it is possible to say that there is not this influence. And it is possible to think that energy absorption capacity is constant approximately in usual range.

(3) In the future, it is necessary to do tensile test to large diameter high strength bolt with waisted shank to change diameter of shank, and to compare with experiment result to optimal diameter of shank

References

(1) Eiichi WATANABE, Kunitomo SUGIURA, Takashi YAMAGUCHI, Shin MOROOKA and Hiroshi SAITOU, Mechanical Behavior of High Strength Bolted Tensile Joints with Multiple Bolt Lines, 1999.3.
(2) British Standards Institution: Specification for high strength frction grip bolts for structural engineering, BS4395 Part3, 1973.10.
(3) Hibbit, Karlsson & Sorensen, Inc. : ABAQUS/Standard User's Manual Vol. I, II, III, Version 5.6, 1996.