Structural Analysis of Taper-Threaded Rebar Couplers

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1. Introduction

Rebar couplers for splicing rebars are used in construction of concrete structures in atomic power plants. The ends of both rebars are usually taper-threaded by thread rolling. Then the rebars are spliced through a taper-threaded rebar coupler.

A number of rebar couplers were developed by the leading companies. The information about the products is available from the company website [1-3]. However, the theory on the taper-threaded coupler is not available. In this paper, the mechanics of the taper-thread was developed to understand the effect of the tightening torque. Structural analysis of our own newly developed rebar coupler was done to improve the strength of the coupler.

2. Methods and Results

In this section the mechanics of the taper-thread is developed first and then the structural analysis of the taper-threaded rebar coupler is done.

2.1 Mechanics of the Taper-Thread

The taper-thread used for each rebar together with the tightening torque and the outer diameter of the matching coupler are listed in Table I. The largest rebar #18 was used as a numerical example. The end of the taper-threaded rebar #18 and its coupler are shown in Fig. 1. Since the taper-thread is double-threaded, the lead is twice the pitch as shown in Fig. 2. The lead angle at the mean diameter section is 2.656° and the taper angle is 2°. The x-axis is aligned in the tangential direction along the thread and the z-axis is aligned in the radial direction.. For the taper angle, the radius decreases by 0.279 mm in each turn as shown in Fig. 3.

Table I: Taper-thread diameters, axial length and pitch, tightening torque and coupler outer diameter

Rebar	D (mm)	D_1 (mm)	D_2 (mm)	L (mm)	p (mm)	T (kg m)	D_o (mm)
#6	19.1	17.7	19.3	22.9	2.5	18.3	29
#7	22.2	20.6	22.5	26.6	2.5	22.4	33
#8	25.4	23.4	25.5	30.5	3.0	27.5	38
#9	28.7	26.5	28.9	34.4	3.0	27.5	43
#10	32.3	29.9	32.6	38.8	3.0	30.6	48
#11	35.8	33.1	36.1	43.0	3.5	30.6	55
#14	43.0	39.4	43.0	51.6	3.5	35.6	65
#18	57.3	52.5	57.3	68.8	4.0	35.6	85

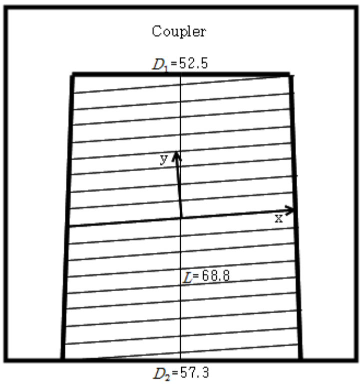


Fig. 1. Tightening of the taper-threaded rebar into a coupler

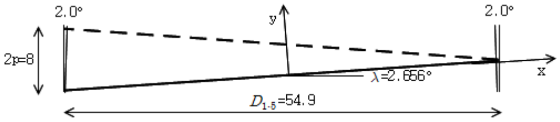


Fig. 2. The lead angle at the mean diameter section and the taper angle

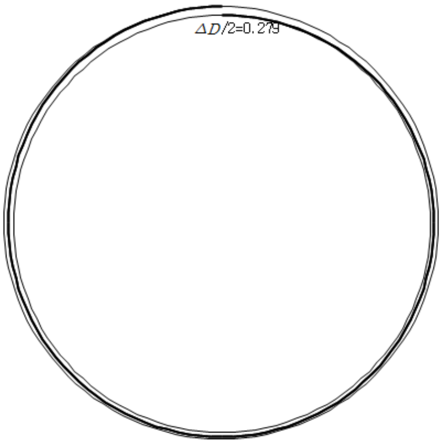


Fig. 3. The taper thread viewed in the axial direction

For the taper-thread, the contact forces act on both flank of the taper-thread as shown in Fig. 4.

Forces in Fig. 5 should be in equilibrium. In Fig. 5(a), the dotted line is the taper-thread. The descending angle α is calculated as 0.093° using the formula

$$\alpha = \sin^{-1}\left(\frac{\Delta D}{2}\frac{\cos\lambda}{\pi D_{1.5}}\right)$$

Friction force is assumed to be proportional to the contact force N, where $N=N_1+N_2$.

The tightening force $F_t=2T/D_{1.5}$

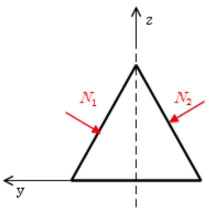
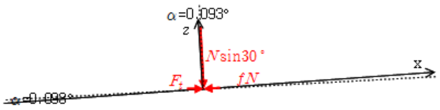
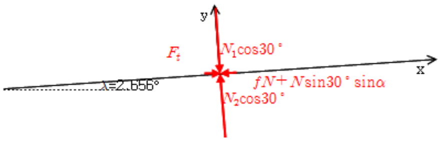


Fig. 4. Contact forces on the flank of the taper-thread



(a) on the x-z plane



(b) on the x-y plane

Fig. 5. Forces in equilibrium

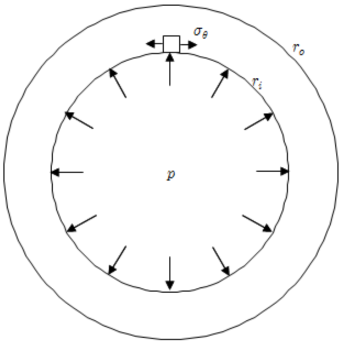


Fig. 6. Thick-walled cylinder subjected to internal pressure

Equilibrium equations are constructed as

$$\begin{bmatrix} f+\sin30^\circ\sin\alpha & f+\sin30^\circ\sin\alpha \\ -\cos30^\circ & \cos30^\circ \end{bmatrix}\begin{Bmatrix} N_1 \\ N_2 \end{Bmatrix} = F_t\begin{Bmatrix} \cos\lambda \\ \sin\lambda \end{Bmatrix}$$

N_1+N_2 were determined by solving the above equations. The radial component N sin 30° act on the inner surface of the coupler. The internal pressure is

$$p=\frac{N\sin30^\circ}{\pi D_{1.5}L}$$

If the tightening torque is excessive, the coupler will yield or fracture due to the excessive circumferential stress as shown in Fig. 6. The circumferential stress is

$$\sigma_\theta = p\frac{r_o^2+r_i^2}{r_o^2-r_i^2}$$

The circumferential stress is listed in Table II. Note that it depends on the coefficient of friction. Note also that it is less than the allowable stress 20 kgf/mm^2 of the material for the coefficient of friction greater than 0.1.

Table II: σ_θ (kgf/mm^2)

f	**#6**	**#7**	**#8**	**#9**	**#10**	**#11**	**#14**	**#18**
0.001	768.1	680.6	539.6	398.2	337.6	223.8	170.1	80.5
0.01	166.8	139.3	111.4	78.2	62.9	42.7	30.2	13.5
0.1	18.9	15.6	12.5	8.7	6.9	4.7	3.3	1.4

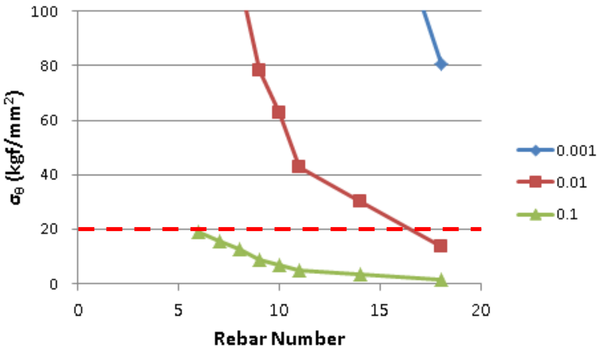


Fig. 7. Circumferential stress in the coupler

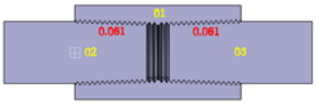
2.2 Structural Analysis of the Rebar Coupler

The tightening of the rebar into the coupler by turning the rebar by 30° is simulated by applying the interference 0.061 mm between the flank of the internal and external threads. In position coupler shown in Fig. 8, the tightening by the turning the nut of the coupler by 15° is simulated by applying the interference 0.061 mm as shown in Fig. 8. On the flank of the parallel thread, only contact condition without any interference is prescribed.

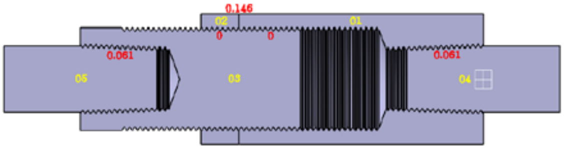
Since the rebar and the coupler are axisymmetric, only the sector shown in Fig. 9 is modeled and the tangential displacement is constrained.

Linear elastic analysis considering contact was done using the general structural analysis module in CATIA V5R18.

The tightening of the taper-threaded rebar developed a uniform stress distribution as shown in Fig. 10~11. On the other hand, the tightening of the nut in the axial direction developed a non-uniform stress distribution as shown in Fig. 10~11. The tensioning also developed a non-uniform stress distribution as shown in Fig. 10~11.

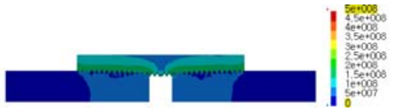


(a) Standard coupler

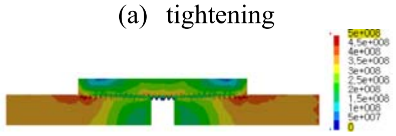


(b) Postion coupler
Fig. 8. Forces in equilibrium

Fig. 9. Finite element model viewed in the axial direction

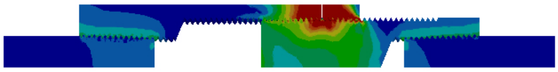


(a) tightening

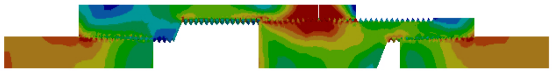


(b) subsequent tensioning

Fig. 10. Von Mises stresses in the standard coupler



(a) tightening



(b) subsequent tensioning

Fig. 11. Von Mises stresses in the position coupler

3. Conclusions

The taper-threaded rebar coupler was analyzed. The tightening of the rebar into the coupler developed a circumferential stress in the coupler. The circumferential stress depends on the coefficient of friction as well as the tightening torque. The circumferential stress is less than the allowable stress 20 kgf/mm^2 of the material for the coefficient of friction greater than 0.1.

The tightening of the rebar into the coupler and the subsequent tensioning was simulated using CATIA. Linear elastic analysis considering contact was done. The tightening of the taper-threaded rebar developed a uniform stress distribution in both standard coupler and position coupler. On the other hand, the tightening of the nut in the axial direction developed a non-uniform stress distribution. Similarly the tensioning also developed a non-uniform stress distribution.

REFERENCES

[1] http://www.erico.com/ Bar to Bar Connections.

[2] http://www.daytonsuperior.com/ Rebar Splicing Products.

[3] http://www.ancon.co.uk/ Reinforcing Bar Couplers