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Friction Coefficient Measurement Test on 13MN Class Tendon of PC Strands for Prestressed Concrete Containment Vessel (PCCV)

Tomoyuki Kitani[a] and Akira Shimizu[b]

[a]*Water Reactor Engineering Department, Nuclear Energy Systems Engineering Center, MHI, Kobe, Japan, e-mail: tomoyuki_kitani@mhi.co.jp*
[b] *Engineering Department, Nuclear Facilities Division, Obayashi Corporation, Tokyo, Japan*

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1 ABSTRACT

Friction coefficient measurement tests were performed using a full scale cylindrical mock-up structure simulating the prestressed concrete containment vessel (PCCV) in order to obtain a friction coefficient of the post tension 13 MN class tendon of 49 PC strands used for the PCCV.

The tendons used for the tests were hoop tendons surrounding the cylindrical wall; i.e. total deviation of about 2 radian. Three tendons were tested.

Each tendon was coated with the corrosion prevention material with a performance comparative to the temporary coating used in the conventional construction of the PCCV before threading into a duct.

Before the tests, 12 kN prestressing force was applied simultaneously to each PC strand independently so that each of the PC strand had the same tension.

From the tests carried out on three tendons, the friction coefficients for deviation were 0.110, 0.124 and 0.125 per radian assuming the friction coefficient for wobbling of the duct as 0.001 per meter.

2 INTRODUCTION

Recent nuclear power plants tend to have larger power with increased design base inner pressure in case of accident, which requires larger tendon capacity for PCCV.

The tendons used in conventional PCCVs are the 10 MN classes whose design base friction coefficients have already been obtained experimentally. However, the friction coefficient of tendons with larger capacity has not been obtained.

The friction coefficient measurement tests in this study were performed using a full scale mock-up structure aiming at obtaining a friction coefficient of 13 MN class tendons expected to use in the future.

3 TEST PLAN

Friction coefficient measurement tests were performed for three 13 MN class tendons using a full scale cylindrical concrete wall simulating cylindrical wall of the PCCV. The tendons, simulating hoop tendons with deviation of about 2 radian, were used with tendon ducts without vertical distortion.

3.1 Tendons

The tendons used in the tests were 13 MN class tendons of 49 PC strands. Each strand with a diameter of 15.2 mm consists of seven wires as defined in the code of ASTM-416 Grade 1860 MPa (270 ksi).

3.2 Full-scale mock-up structure

The mock-up structure, with two buttresses, is a cylindrical RC structure with 47,920 mm in inner diameter, 700 mm in wall thickness and 2,750 mm in height.

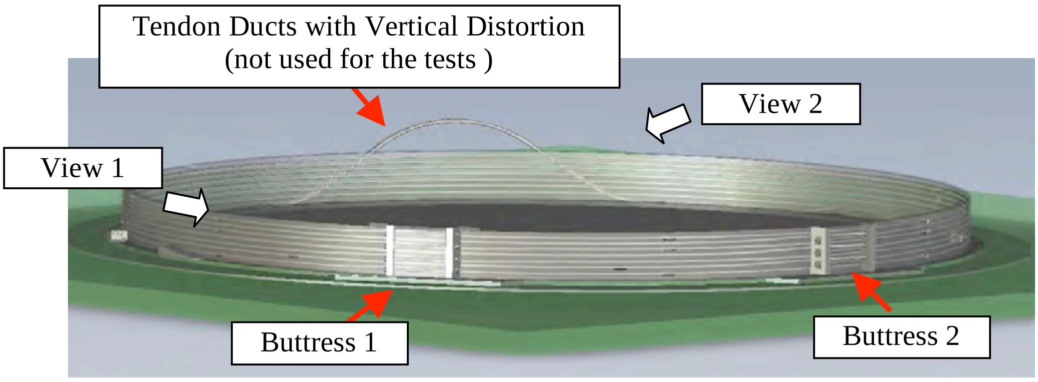
Three and four tendon ducts surround the cylinder (2 radian) at each anchorage of the two buttresses and tendons are anchored at both ends of the buttresses.

Photo 1 shows the cylindrical concrete mock-up structure and Photo 2 shows the buttress and anchorage details.

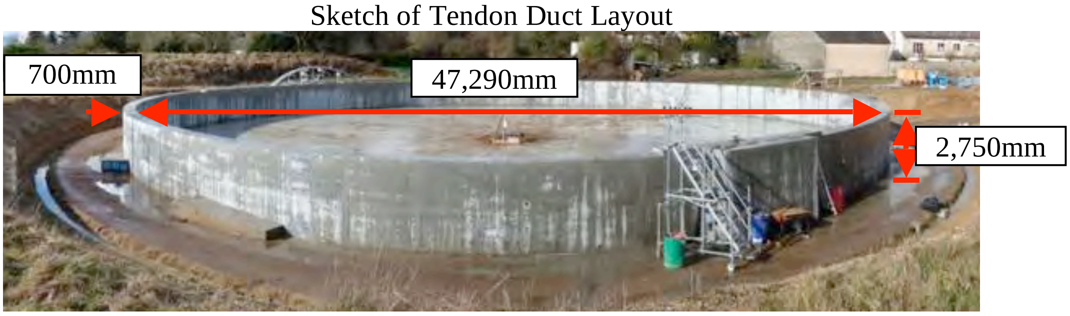
Three tendons among seven tendons embedded in the cylindrical concrete mock-up structure were used in the tests. Description of the tendon ducts is shown in Table 1.

The three tendon ducts used in the tests were electro-coated with zinc.

Inner diameter of each tendon duct is 160 mm.



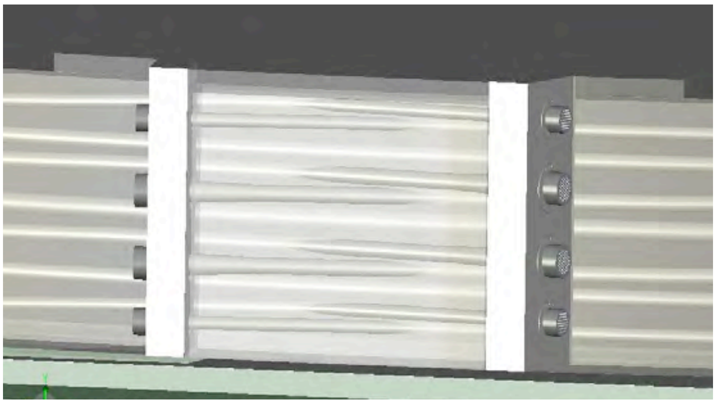
Sketch of Tendon Duct Layout



General View from View 1

General View from View 2

Photo 1 Full-scale Mock-up Structure



Sketch of Buttress and Tendon Anchorage

(1) NCs (2)Nc

Buttress 1 Anchorage Type

Photo 2 Buttress and Anchorage Details

Table 1 Tendon Ducts Description

No.	Anchorage Type	Duct Quality	Total Length (m)	Radius of Center of Wall (m)	Total Deviation (radian)
2	NCs	Electro-coated Zinc 25 m	157.995	24.460	6.465
4W	NCs	Electro-coated Zinc 25 m			
5	Nc	Electro-coated Zinc 25 m			

3.3 Test procedure

3.3.1 Threading PC Strand into Tendon Duct

The PC strands were threaded into the tendon ducts according to the following procedure;

1. Set a coiled PC strand to the uncoiler, and then thread it into the tendon duct one by one using a pushing machine,
2. Passing through a grease bath before threading into the tendon duct to coat a corrosion prevention material in compliance with the ASME Sec. III Div.2 (hereafter called ASME code) CC-2442.2 Temporary Coatings,

3. Stop the pushing machine when end of the PC strand appears by 200 mm from the anchor head at the exit on the other side of the buttress, and draw back the PC strand to adjust the appeared end to be about 100 mm using the pushing machine to eliminate slacking, and

4. In order to reduce dispersion in tension in each of the 49 PC strands in a tendon, each PC strand is pre-tensioned simultaneously at 12 kN. Table 2 shows the mean value and standard deviation of the tensions in the strands measured with magnetic load-cell at the target load of 208.56 kN per strand which is allowable stress of 0.80 Fp (Fp=260.7 kN per strand) by ASME code. Figure 1 shows the distribution of the tensions in the strands for the tendon duct 4W.

3.3.2 Measuring of Tensioning Force of Tendon

Load was applied to the tendons and tensioning force of tendons measured according to the following procedure;

1. Install a tension jack at the active side so that the load is directly transmitted to the anchor head, and another tension jack at the passive side so that load is transmitted to the anchor plate through the chair,

2. Apply an initial tension with the tension jack at the passive side until the anchor head is separated from the bearing plate, avoiding direct loading to the anchor head,

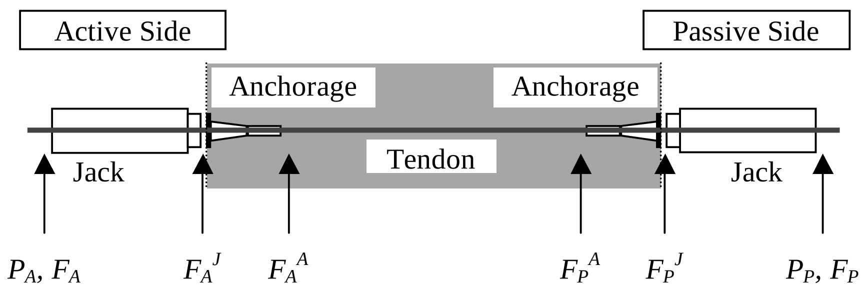
3. Apply an initial tension with the tension jack at the active side to the about 10 % of the target load (50 bar), and then increase the load to the target load in increments of about 10 % load (50 bar), by controlling the load with a pressure; and

4. Keep the load at each load step for 90 seconds, and then record the load at both active and passive sides.

5. The target load shall be 10.219 MN (=208.56kN*49) at the active side of the tendon. The loads and pressures of the jacks shall be 10.373 MN and 438 bar at the duct 2 and 4W, and 10.475 MN and 442 bar at the duct 5 respectively. The difference among the ducts comes from the difference in the loss at the anchorages; 0.18 % for the anchorage at duct 2 and 4W (anchorage type NCs) and 0.53 % for the anchorage at duct 5 (anchorage type Nc).

3.4 Calculation of Friction Coefficients

Friction coefficients were calculated based on the measurements obtained from the tests performed according to the procedure described above, taking the losses at the tension jacks and anchorages.



(Calculation of load transmission coefficients at the tension jacks and anchorages)

$$K_A = (1 + L_A),\ K_J = (1 + L_J) \qquad (1)$$

Where,

K_A, K_J: Load transmission factors at the jacks and anchorages

L_A, L_J: Losses at the jacks and anchorages obtained by separate tests

(Calculation of loads taking the loss at the jacks into account)

$$F_A^J = P_A \times (1 - L_J) = P_A / K_J,\ F_P^J = P_P\ (1 + L_J) = P_P\ \ K_J \quad (2)$$

Where,

F_A^J, F_P^J: Load at the outer boundary of the anchorage at the active and passive sides

$P_{A,}$, P_P: Measured loads (bar) at active and passive sides

($F_{A,}$, F_P: Jack loads (kN) at active and passive sides calculated by [Measured loads (bar)]*[piston area of jack(=236,900mm^2)]*10,000)

(Calculation of loads taking the losses at the jacks and anchorages into account)

$$F_A^A = F_A^J\ (1 - L_A) = P_A / (K_A K_J),\ F_P^A = F_P^J\ (1 + L_A) = P_P K_J K_A \quad (3)$$

Where,

F_A^A, F_P^A : Loads at the inner boundary of the anchorages at the active and passive sides

(Calculation of load transmission coefficients K taking the friction loss in the tendon duct into account)

$$K = F_P^A / F_A^A = (P_P / P_A)\ K_A^2\ K_J^2 \quad (4)$$

Given the ratio of measurements between the active and passive loads as K, and the factors relevant to the losses at the tension jacks and anchorages as f_C, then,

$$Kobs = P_P / P_A \quad (5)$$

$$f_C = 1 / (\ K_A^2\ K_J^2\ ) \quad (6)$$

$$K = Kobs / f_C \quad (7)$$

The load transmission factor K can be calculated by the following equation using the friction coefficients for deviation;   and for wobbling of the duct;   ,

$$K = \exp\ (- \quad - \quad L\ ) \quad (8)$$

Assuming a certain value of   ,   can be obtained by the following equation.

$$= -(\ln\ (K) + \quad L) / \quad (9)$$

4 TEST RESULTS

4.1 Friction Coefficient

Table 3 shows friction coefficients obtained in this study. The friction coefficient for deviation,   , at the target load were 0.110 per radian for the duct 2, 0.125 per radian for the duct 4W and 0.124 per radian for the duct 5, assuming the friction coefficient for wobbling   ＝0.001 per meter.

Figure 2 shows the relation between the loads at the active side and the friction coefficients. The figure indicates that the friction coefficients do not change significantly but tends to increase with the increase of the load at the active side for the duct 2, 4W and 5 in a similar manner.

4.2 Relation between the jack pressures at the active and the passive sides

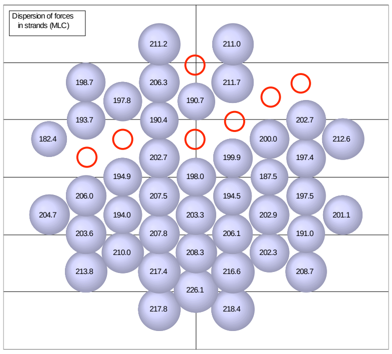
Figure 3 shows the relation between the jack pressures at the active and passive sides. The figure indicates that the jack pressures at the active and passive sides increase linearly in the duct 2, 4W and 5, however the slope in the duct 2 is larger than the others, suggesting larger load transmission to the passive side (smaller friction coefficient) in the duct 2.

In addition, for the duct 2, the relation between the jack pressures at the active and passive sides is more consistent, suggesting smoother load transmission, than that in the duct 4W and 5, in particular in the range near the target load.

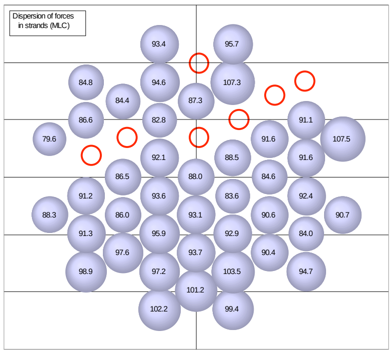
Table 2 Mean and Standard Deviation (   ) of Tensile in Each Strand at Target (Maximum) Load

	Duct 2	**Duct 4W**	**Duct 5**
Mean (kN)	205	204	207
(kN)	11.1	9.2	9.9
Max. (kN)	231	226	230
Min. (kN)	182	182	186

Note: means standard deviation



at 200 bar: (Mean: 92.2 kN, : 6.4 kN, Max: 108 kN, Min: 80 kN)



at 438 bar (Target load):(Mean: 204kN, : 9.2 kN, Max: 226 kN, Min: 182 kN)

Figure 1 Distribution of Tensile in the Duct 4W (Red marks indicate PC strand not measured due to the trouble of the instrument.)

Table 3(1) Friction Coefficient at Target Load Obtained from Tests

Duct ID	L_A	L_J	P_A **(bar)**	P_P **(bar)**	L **(m)**	**(radian)**	**(/m)**	***Kobs***	K	**(/rad)**
2	0.0018	0.0083	437	180	157.995	6.465	0.001	0.412	0.420	0.110
4W	0.0018	0.0083	438	163	157.995	6.465	0.001	0.372	0.380	0.125
5	0.0059	0.0083	443	165	157.995	6.465	0.001	0.372	0.383	0.124

Note: the variables in the table are defined in the section 3.4.

Table 3(2) Friction Coefficient at Each Load Step Load Obtained from Tests (=0.001/m)

Step	**Duct 2**			**Duct 4W**			**Duct 5**		
	F_A **(kN)**	F_P **(kN)**	**(/rad)**	F_A **(kN)**	F_P **(kN)**	**(/rad)**	F_A **(kN)**	F_P **(kN)**	**(/rad)**
1	3,506	1,611	0.093	3,554	1,492	0.107	3,530	1,469	0.107
2	4,620	2,108	0.094	4,762	1,943	0.111	4,714	1,895	0.112
3	5,899	2,582	0.100	5,946	2,393	0.113	5,946	2,345	0.115
4	5,828	2,606	0.097	5,875	2,369	0.113	5,875	2,345	0.113
5	7,060	3,056	0.102	7,083	2,843	0.114	7,083	2,819	0.114
6	8,220	3,530	0.103	8,292	3,246	0.118	8,292	3,246	0.116
7	9,405	3,956	0.106	9,500	3,672	0.119	9,452	3,648	0.118
8	10,353	4,264	0.110	10,376	3,861	0.125	10,495	3,909	0.124

Note1: The variables in the table are defined in the section 3.4.

Note2: After step 3, the jack stroke was returned to initial position bearing the tension of the tendon by the

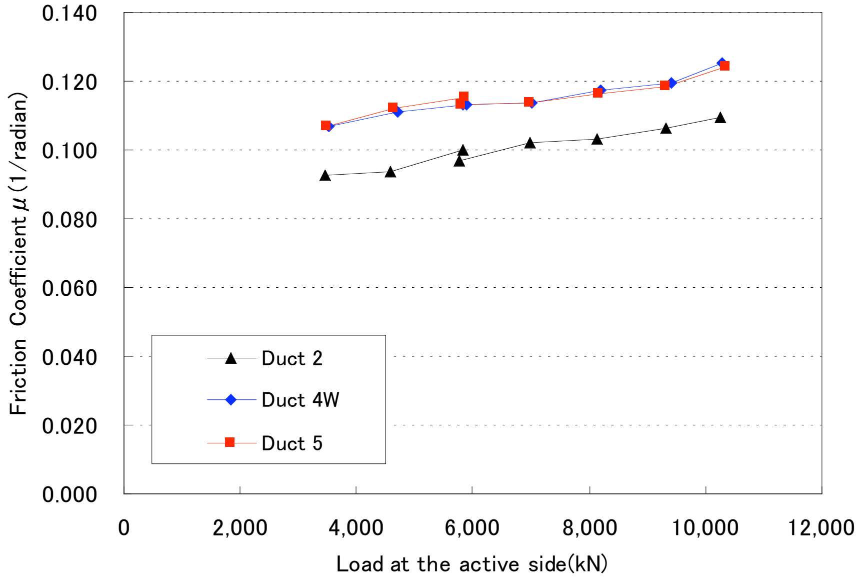


Figure 2 Comparison of Friction Coefficients at Each Load Step (=0.001/m)

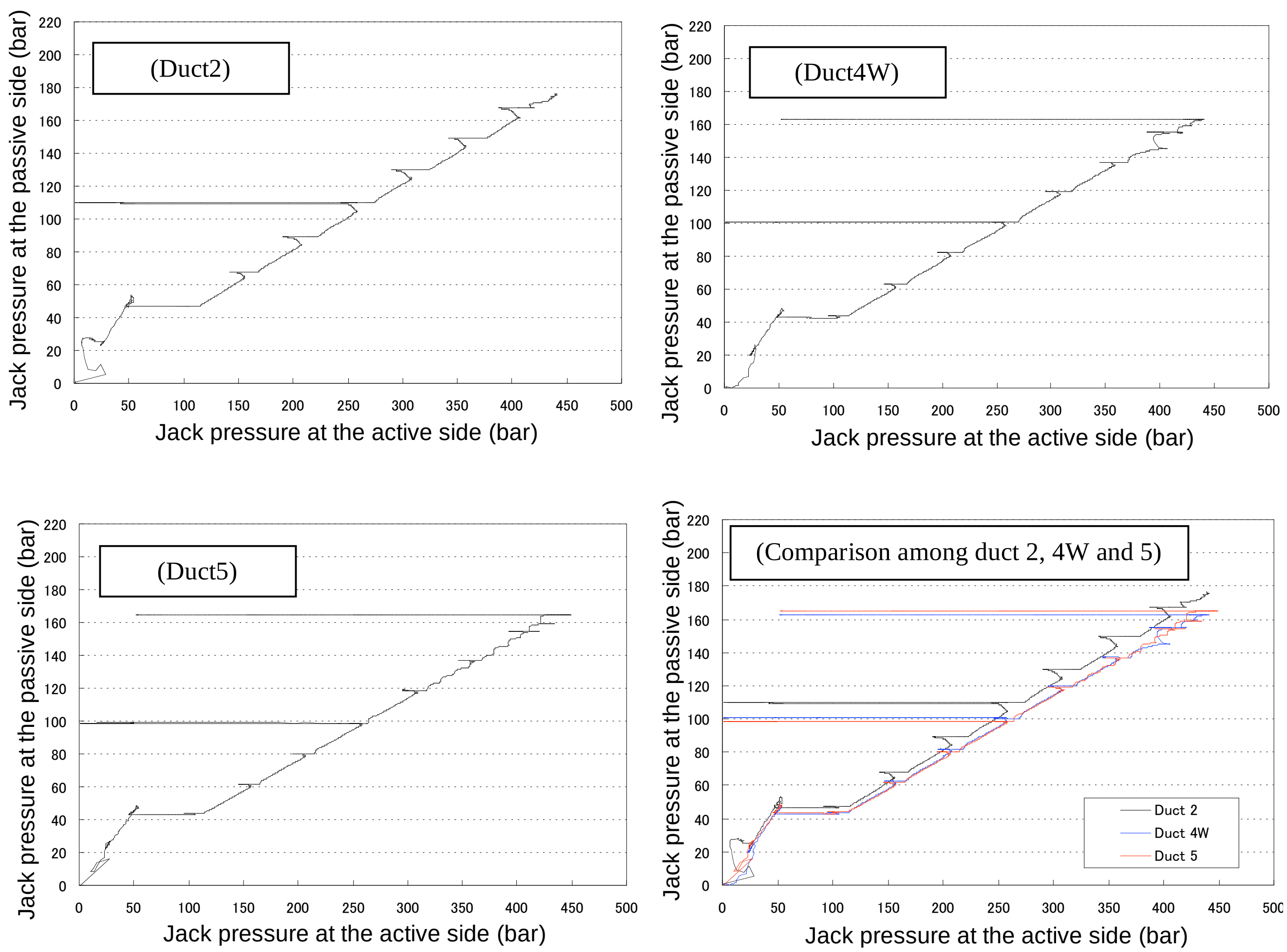


Figure 3 Relation between Jack Pressures at Active and Passive Sides

5 CONCLUSION

Friction measurement tests were performed for the PC strands post tension 13 MN class tendons using the full scale concrete mock-up structure simulating the cylindrical wall of the PCCV. Three tendons simulating hoop tendons with deviation of 2 radian were used for the tests.

Friction coefficients for deviation, , for the three tendons were 0.110, 0.124 and 0.125 per radian (assuming , the friction coefficient for wobbling of the duct, as 0.001 per meter), which are smaller than 0.14 per radian (=0.001 per meter) that has been used in the design of the PCCV using 10 MN class tendon in Japan.

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