INVESTIGATION ON ULTIMATE STRENGTH EVALUATION OF SNUBBER IN PIPING SYSTEM OF JAPANESE NPP

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ABSTRACT

It is confirmed that strength of snubbers which have been used in piping systems of Japanese NPP, are one and a half times as strong as one's fixed capacity. However, it is expected that snubbers have above two times strength of one's fixed capacity.

In this study, destructive experiments were conducted, ultimate strength evaluation of snubber was accomplished. This study was carried out by 10 Japanese utilities and 3 plant manufacturers as joint research.

Snubbers consist of functional elements such a pipette valve except strong elements. It is needed to confirm whether their functional elements preserve one's functions for seismic load in the case of evaluating ultimate strength of snubber. Therefore, destructive experiments were conducted for snubbers used in piping systems of Japanese NPP from a point of functional preservation. Further more, destructive experiments were conducted from a point of buckling.

Based on the experimental results, ultimate strength evaluation of snubber have been investigated, according to study on differences between ultimate strength obtained by destructive experiments and expected ultimate strength based on the strength of materials.

INTRODUCTION

It is confirmed that strength of snubbers which have been used in piping systems of Japanese NPP, are one and a half times as strong as one's fixed capacity. The strengths of snubbers were guaranteed by tests in development and inspections before supply. There are few data on the ultimate strengths of snubbers which have been verified.

In this study, destructive experiments were conducted to accomplish ultimate strength evaluation of snubber.

OUTLINE OF STUDY

Outline of study is shown in Figure 1 in order to investigate Ultimate Strength Evaluation of Snubber in piping system of Japanese NPP.

① Extract snubber type
② Study on disorder factor of oil-hydraulic snubber and mechanical snubber by analysis of disorder factor
③ Select snubber type for investigation on functional preservation of snubber
④ Extract examination elements based on analysis of disorder factor
⑤ Assume margin of snubber based on the strength of materials and functional preservation
⑥ Group snubber from a point of the most weak element
⑦ Decide capacity of snubber from some snubbers in every group for experiment
⑧ Conduct both destruction experiments from a point of functional preservation and buckling
⑨ Investigations comparatively on between experimental results and assumptive margins
⑩ Improve assumptive method based on above investigations
⑪ Accomplish ultimate strength evaluation of snubber in piping system of Japanese NPP

ANALYSIS OF DISORDER FACTOR

Snubber kinds are divided oil-hydraulic snubber and mechanical snubber. A number of snubber which has been used in the piping systems of Japanese NPP were made by SANWA TEKKI CO. and NHK SPRING CO.,LTD. Both companies have manufactured several types of snubber. The types of snubber in the piping systems of Japanese NPP are shown in Table 1.

In this study, at first it is needed to be accounted for evaluation items in order to accomplish ultimate strength evaluation of snubber. Therefore, it is need to be analyzed disorder factor of both snubber kinds from a point of functional preservation during and after earthquake. Table 2 shows disorder factor of both snubber kinds. It is considered that the disorder factors can be applicable for the snubbers made by both companies.

Although there are a few differences in detail between same kinds of both companies, they mostly consist of the same elements. Accordingly, it is considered that ultimate strength evaluation of snubber accomplished based on investigation of a representative snubber can be developed others.

SELECTION OF SNUBBER FOREXPERIMENTS

Selection flow of snubbers for experiments is shown in Figure 2.

① Extract examination elements based on analysis of disorder factor
② Assume margin of snubber based on the strength of materials and functional preservation
③ Group snubber from a point of the most weak element
④ Decide capacity of snubber from some snubbers in every group for experiment

Based on flow in Figure 2, Snubbers selected are shown in Table 3. Figure 3 shows the structural drawing of oil-hydraulic snubber and mechanical snubber.

Table 1 Types of snubber in Japan

Manufacturer	Kind	Type
SANWA	Oil-hydraulic	SN
		SHP
		HSP
		HS
		VD
	Mechanical	SMS
NHK	Oil-hydraulic	NMB
		Old type
	Mechanical	ODP

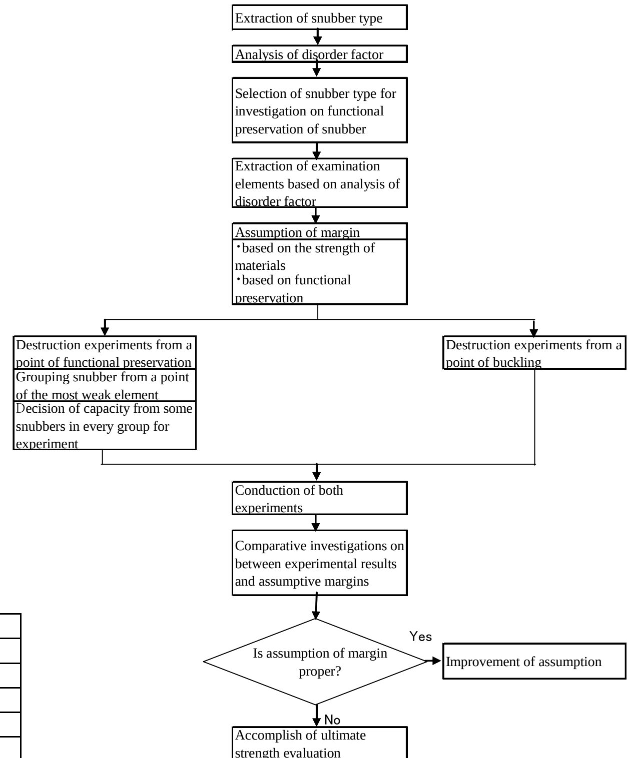
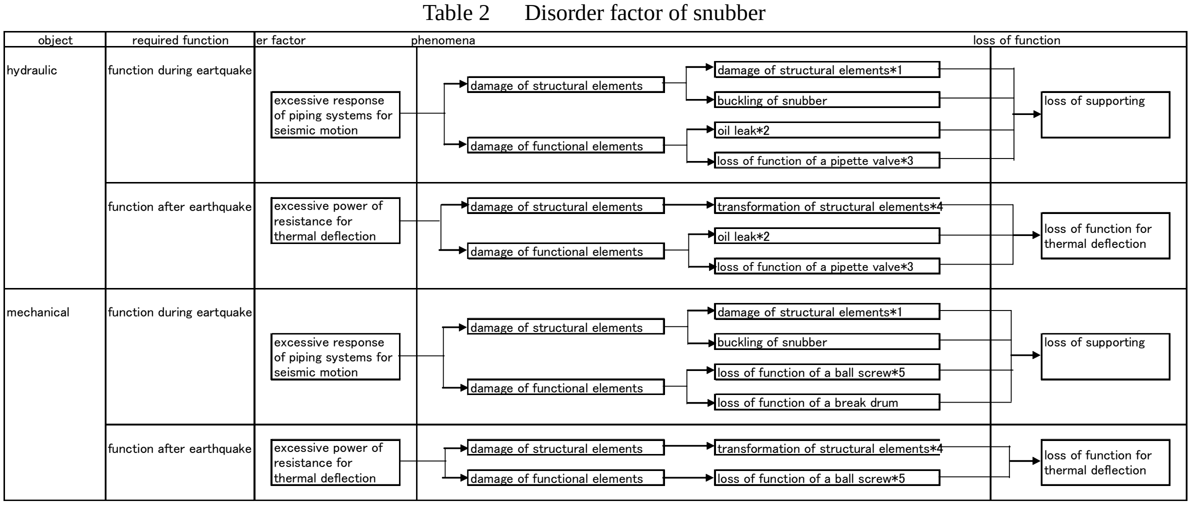


Figure 1 Investigation Flow for Ultimate Strength Evaluation of Snubber

Table 2 Disorder factor of snubber



*1:Strength evaluation of structural elements of every snubber
*2:Oil leak is considered leak in or out boundary. In the case of leak in boundary, it is cinsidered that required power of resistance cannot be obtained by decrease of seal function in a part of piston. In the case of leak out boundary, it is considered that required power of resistance cannot be obtained by decrease of seal function between piston and rod cover.
*3:Loss of function of a pipette valve is considered due to a change of spring resistance. It is considered that required power of resistance cannot be obtained during earthquake. It is considered that excessive power of resistance for thermal deflection is caused after earthquake. However, seismic load which make spring resistance change cannot be caused during earthquake.
*4:Transformation of structural elements cause excessive power of resistance for thermal deflection. For example, transformation of piston rod, load column and so on.
*5:It is considered that loss of supporting function is caused by pressure-split of ball in ball screw during earthquake. It is considered that excessive power of resistance for thermal deflection is caused . by one after earthquake

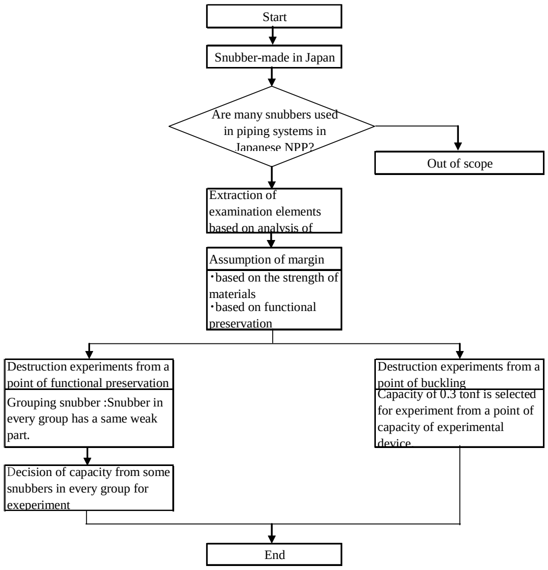
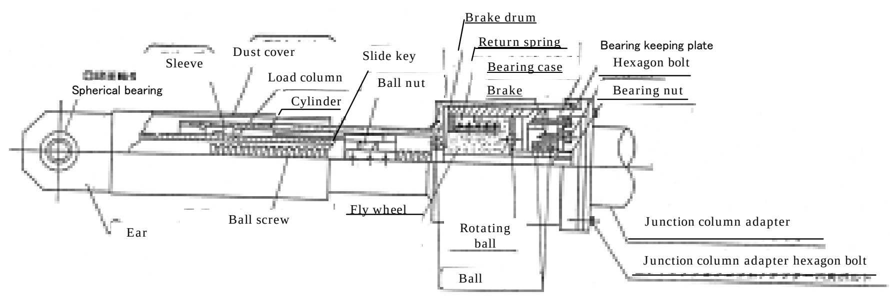


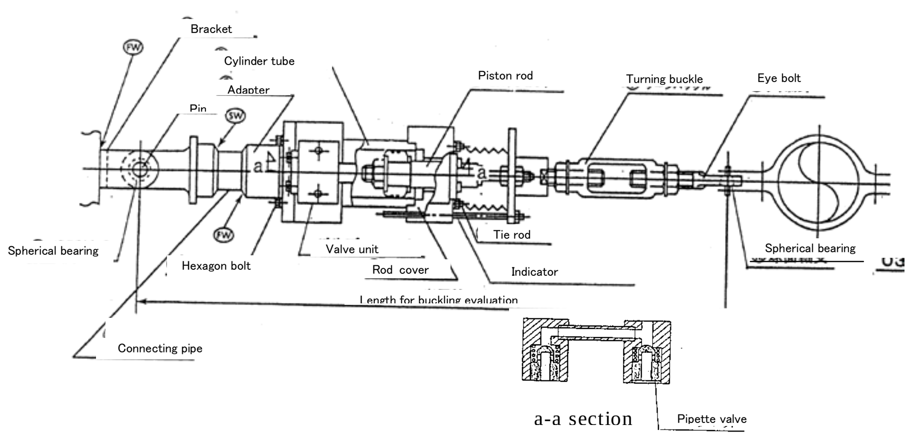
Figure 2 Selection Flow of Snubber for Experiment

Table 3 Snubbers selected for experiments

Experiment	Type	Most weak part	Number of specimen
Function preservation	SMS-03	Hexagon bolt	1
	SMS-1	Connecting tube	1
	SMS-3	Ball screw	3
	SMS-6	Bearing nut	1
	SMS-10	Pin of direct attach bracket/ Pin of universal bracket	1
	SN-03	Ear of rod end	1
	SN-3	Connecting pipe(welded part)	3
	SN-6	Junction column adapter(welded part)	1
	SN-16	Direct ear	1
	SHP-03	Part of seal	1
	SHP-3	Eye bolt/Connecting pipe	3
	SHP-16	Turning buckle	1
	NMB-003	Rear bracket	1
	NMB-030	Rear bracket	1
	ODP-003	Adapter	1
	ODP-030	Piece of extension	1
Buckling	SMS-03	—	1
	SN-03	—	1
	SHP-03	—	1



(a) Mechanical snubber(type:SMS)



(b) Oil-hydraulic snubber(type:SHP)

Figure 3 Structure drawing of snubber

DESTRUCTIVE EXPERIMENTS

In this study, destructive experiments were conducted in order to evaluate functional preservation and buckling of snubber.

(1) Destructive experiments for evaluation of functional preservation

Snubbers must preserve the function shown as below during and after earthquake.

During earthquake：snubber preserve rigidity required by design specification
After earthquake ：snubber preserve low power of resistance required design specification

Therefore, experiments as shown below were conducted in order to confirm above functions.

Confirmation of functional preservation duringearthquake：measurement of rigidity in cyclicexcitation
Confirmation of functional preservation after earthquake：measurement of resistance for low speed

Destructive experiments were conducted to combine measurement of rigidity in cyclic excitation every load level and measurement of resistance for low speed load. Increase of load level were continued up to confirm damage of structural elements or malfunction. The conditions of both experiments are shown as following. Both experimental devices are shown respectively in Figure 4 and Figure 5.

Measurement of rigidity in cyclic excitation（frequency：9Hz, number of cyclic excitations：100)
Measurement of resistance for low speed load（speed：2.1mm/sec）

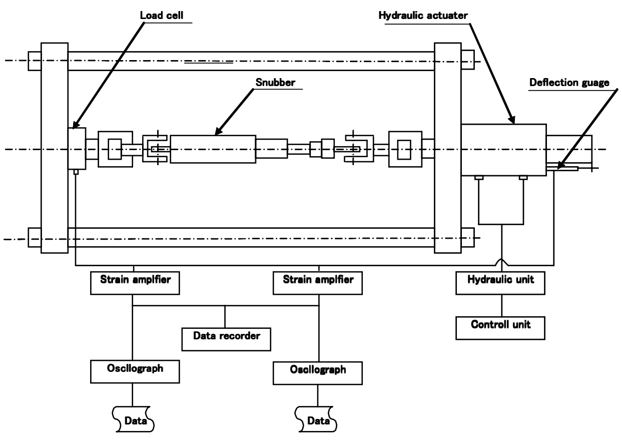


Figure 4 Experimental Device of Destructive Experiments for Measurement of Rigidity in Cyclic Excitation

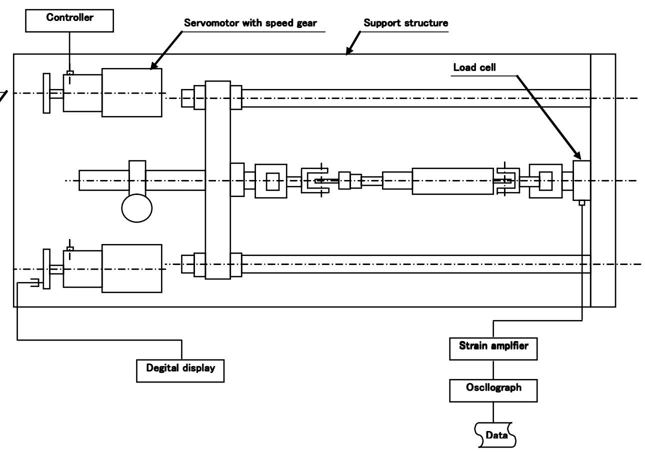


Figure 5 Experimental Device of Destructive experiments for Measurement of Resistance for Low Speed Load

(2) Destructive experiments for evaluation of buckling

Destructive experiments were conducted by increasing deflection of compression direction, and were continued up to confirm buckling of a snubber. Experimental device is shown in Figure 6.

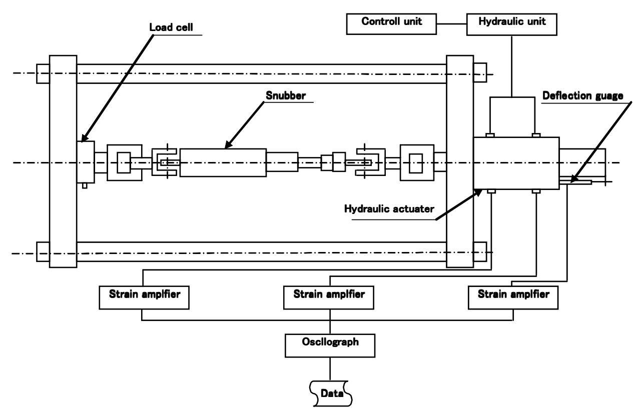


Figure 6 Experimental Device of Destructive experiments for Buckling

EXPERIMENTAL RESULTS

(1) Destructive experiments for evaluation of functional preservation

The results of destructive experiments were shown in Table 2. It is found that all snubbers have over twice ultimate strength comparing to ultimate strength assumed. Further, it is found that small capacity of snubber has more margin than large capacity of one.

(2) Destructive experiments for evaluation of buckling

The results of destructive experiments were shown in Table 3. Assumption of ultimate strength is besed on Euler formula. It is found that all assumptions for buckling loads cannot be evaluated safely. Especially, as there is the smallest section of SHP in the middle part of snubber, ultimate strength of SHP for buckling load is lower than one of others.

Table 2 The results of destructive experiments for evaluation of functional preservation

Type	Capacity (kN)	Assumption		Result		Rate (Result / Assumption)	Remark
		Ultimate strength (kN)	Damage element	Ultimate strength (kN)	Damage element		
SMS-03	2.94	17.64	Hexagon bolt	27.09	Angular spherical bearing	1.53	
SMS-1	9.80	53.90	Ball screw	44.84	Angular spherical bearing	0.83	
SMS-3	29.40	88.20	Connecting tube	88.02	Spherical bearing	0.99	Standard length
				98.12	Bearing keeping Plate/Hexagon bolt	1.11	Standard length -25mm
				85.04	Spherical bearing	0.96	Standard length +25mm
SMS-6	58.80	182.28	Bearing nut	153.91	Bearing keeping plate	0.84	
SMS-10	98.00	274.40	Pin of direct attach bracket/Pin of universal bracket	199.02	Angular spherical bearing	0.72	
SN-03	2.94	24.11	Ear of rod end	20.36	Piston rod	0.84	Standard length
SN-3	29.40	73.50	Connecting pipe (welded part)	91.00	Spherical bearing	1.23	Standard length -25mm
				93.39	Spherical bearing	1.27	Standard length +25mm
				89.3	Spherical bearing	1.21	
SN-6	58.80	135.24	Junction column adapter(welded part)	144.07		1.06	
SN-16	156.80	329.28	Direct ear	408.90	Spherical bearing	1.24	
SHP-03	2.94	32.63	Part of seal	-17.48*		0.53	*:Compression load
SHP-3	29.40	105.84	Eye olt/ Connecting pipe	69.33	Turn buckle and Piston rod	0.65	Standard length
				106.57	Angular spherical bearing	1.00	Standard length -25mm
				73.14	Turn buckle and Piston rod	0.69	Standard length +25mm
SHP-16	156.80	360.64	Turning buckle	387.95	Spherical bearing	1.07	
NMB-003	2.94	15.19	Rear bracket	20.58	Loose of nut	1.35	
NMB-030	29.40	67.39	Rear bracket	76.84	Buckling of load cylinder	1.14	
ODP-003	2.94	17.37	Piston rod	14.47	Piston rod	0.83	
ODP-030	29.40	83.02	Ear/Extension	-118.89*	Spherical bearing	1.43	*:Compression load

Table 3 The results of destructive experiments for buckling

Type	Capacity (kN)	Assumption	Result		Rate (Result / Assumption)	Distance between pins (mm)
		Ultimate strength (kN)	Ultimate strength (kN)	Damage element		
SMS-03	2.94	73.47	57.86	bending of connecting pipe	0.78	915
SN-03	9.80	22.40	19.41	bending of screw of piston rod	0.86	1340
		60.39	53.39	bending of screw of piston rod	0.88	670
SHP-03	2.94	20.70	14.55	bending of screw of piston rod	0.70	1285
		32.26	17.48	bending between turn buckle and piston rod	0.54	875
SHP-3	29.40	189.81	107.71	bending between turn buckle and piston rod	0.56	1045
		162.17	90.12	bending between turn buckle and piston rod	0.55	1070

STUDY OF EXPERIMENTAL RESULTS

Experimental results were divided into below categories.

① No damage for over ultimate strength assumed
② Damage for below ultimate strength assumed
③ Damage or loss of function except expected part

Considered material data at manufacturing and so on, ultimate strength evaluated and experimental result were compared. Corrective methods were investigated on difference between both ultimate strengths.

a. No damage for over ultimate strength assumed

a-1. Hexagon bolt of SMS

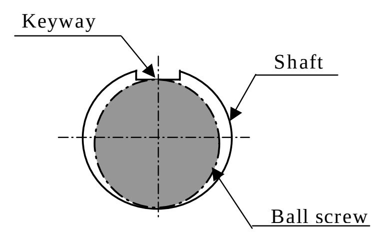
Hexagon bolt of SMS-3-2 was damaged at maximum loading 148.42 kN, and existing strength of one was 179.12 kN. A ratio of maximum load to existing strength was 0.83. Therefore, corrective efficient 0.8 was adopted in evaluation for hexagon bolt of SMS.

$$F = 0.8 \times Su \times A$$

F : Ultimate strength
Su : Design tensile strength
A : Effective area of screw
0.8 : Corrective efficient

a-2. Ball screw of SMS

Strength of ball screw has been calculated by an area of shaded portion. Strength of ball screw based on experimental result of SMS-3 was 0.7 times as strong as strength calculated by an area deducted an area of keyway from an area of shaft. Therefore, corrective efficient 0.7 was adopted in evaluation for ball screw of SMS.



$$F = 0.7 \times Su \times A$$

F : Ultimate strength
Su : Design tensile strength
A : Effective area of ball screw
0.7 : Corrective efficient

a-3. Evaluation for shear stress of pin

Shear strength of pin has been calculated by a mean stress. Shear strength of based on experimental result of SMS-3 was 0.77 times as strong as strength calculated by a mean stress. Therefore, corrective efficient 0.7 was adopted in evaluation for shear strength of pin.

$$F = 0.7 \times (Su / \sqrt{3}) \times A$$

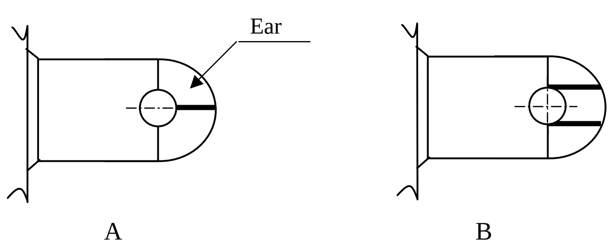
F : Ultimate strength
Su : Design tensile strength
A : Effective area of pin
0.7 : Corrective efficient

a-4. Capacity of seal

Although capacity of seal was based on minimum capacity approved by manufacturer, it is found that capacity of seal has over three times as large as minimum capacity from experimental result. Therefore, corrective efficient 3 was adopted in evaluation for capacity of seal.

a-5. Evaluation for shear stress of ear and plate of rod end

Modeling of evaluation was changed A to B.



b. Damage for below ultimate strength assumed/ Damage or loss of function except expected part

b-1. Transformation of bearing keeping plate

Ultimate strength evaluated for bending of a bearing keeping plate and maximum load caused transformation were compared, corrective efficient 0.9 was adoped in evaluation for transformation of a bearing keeping plate

$$F = 0.9 \times \frac{fb}{\beta} \times h^2$$

F : Ultimate strength
fb : Bending strength
h : Thickness of bearing keeping plate
β : b/a

0.9 : Corrective efficient

b-2. Split of spherical bearing with brim

Ultimate strength evaluated and experimental results were compared, corrective efficient 0.8 was adopted in evaluation for split of angular spherical bearing with brim.

b-3. Oil leak of SN

Tightening force of tie rod and maximum tensile force are compared, corrective efficient 0.7 is adopted in evaluation for axial force of tie rod.

$$F = 0.7 \times \frac{Tf}{0.2d}$$

F : Corrected axial force
0.7 : Corrective efficient
Tf : Tightening torque
d : Major diameter of external threads

b-4. Buckling

Experimental results in Table 2 and Table 3, and data of the past were plotted in Figure 5. Figure 5 was arranged by a ratio of distance of the smallest section and pin to distance between pins. According to Figure 7, ratio decrease as the smallest section approach to the center of snubber. Therefore, corrective efficient were decided as follows.

Corrective efficient : 0.7 ($0<l/L<0.25$)
Corrective efficient : 0.5 ($0.25 \leq l/L \leq 0.5$)
l : distance between the smallest section and pin
L: distance between pins

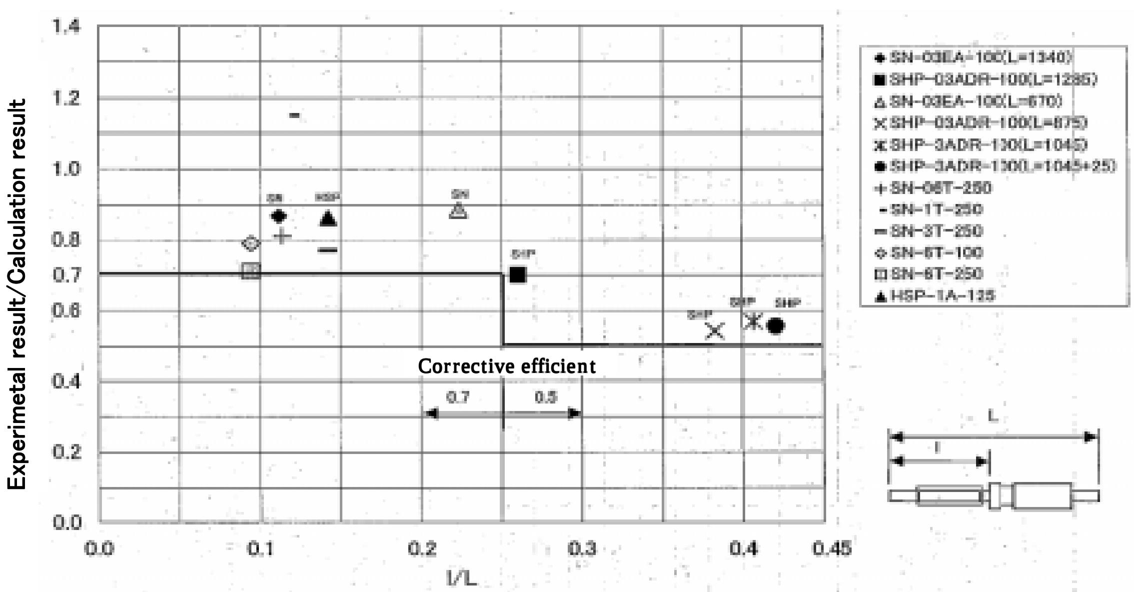


Figure 7 Corrective efficient for buckling evaluation(Euler formula)

b-5. Capacity of angular spherical bearing

Although capacity of angular spherical bearing was based on minimum capacity approved by manufacturer, it is found that capacity of angular spherical bearing has over 16 times as large as minimum capacity from experimental result. Therefore, corrective efficient 16 was adopted in evaluation for capacity of angular spherical bearing.

b-6. Loose of fly wheel nut

It is decided that loose of fly wheel nut is evaluated by shear stress of screw.

INVESTIGATION ON EVALUATION OF ULTIMATE STRENGTH

Evaluation method on ultimate strength of snubber was summarized as follows.

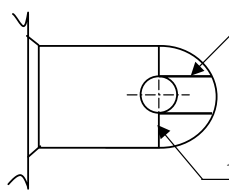
【Evaluation method of strength】

Approved tensile load (Pa)=Min(0.7×Su×A, 1.2×Sy×A)

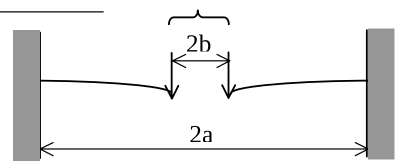
Approved shear load (Sa)=Min(0.7×Su/$\sqrt{3}$×A, 1.2×Sy/$\sqrt{3}$×A)

Su : Design tensile stress(N/mm^2)
Sy : Design yield stress(N/mm^2)
A : Cross-sectional area

Besides, cross-sectional area at ear is used as shown below.



Bending load of plate (*F*)



$$F = 0.9 \times \frac{fb}{\beta} \times h^2$$

F : Ultimate strength
fb : Bending strength
h : Thickness of bearing keeping plate
β : b/a
0.9 : Corrective efficient

Ultimate load of angular spherical bearing : minimum capacity approved by manufacturer is multiplied by corrective efficient(16).

【Evaluation method of buckling】

Strength which is calculated by Euler formula is multiplied by corrective efficient as shown below, is ultimate strength for buckling.

$$F = \beta \times \pi^2 \times \frac{E \times I}{L^2}$$

F : Ultimate strength
E : Young's modulus
I : Moment of inertia of area
L : Distance of between pins
β : Corrective efficient

Corrective efficient : β=0.7 (0<l/L<0.25)
Corrective efficient : β=0.5 (0.25≤l/L≤0.5)
l : distance between the smallest section and pin
L: distance between pins

SUMMARY OF RESULTS

Based on experimental results, evaluation formulas on ultimate strength of snubber were accomplished. Ultimate strength of every snubber in the piping systems of Japanese NPP were calculated by using these evaluation formulas. As a result, it is found as shown below.

・the ratio of ultimate strength to capacity decrease as capacity increase

ACKNOWLEDGMENTS

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