Experimental Study on RCCV of ABWR Plant
Part 8: Experiments on Liner Anchor and Penetration

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1. INTRODUCTION

This paper summarizes the study of shear load and deformation characteristics of continuous tee liner plate anchors, and the study of high temperature pipe penetrations in RCCV (Reinforced Concrete Containments Vessel). The major design conditions which produce liner compression and tention are the strain imposed by the overall deformations of the containment and the strain due to thermal expansion of the liner plate itself. These compressive strains can cause large unbalanced loads in the liner plate which result in shear forces acting on the liner plate anchors at geometric discontinuities. Shear force versus deformation test data are necessary to assure that the design is adequate under the ocnditions of deformation and maximum unbalanced load. Objectives of the shear force test for liner anchors are as follows.

(1) To determine the characteristics of the load-deflection curve of the liner anchor.
(2) To develop idealized load-deflection curves for design, based on studies of those characteristic.

Concrete temperature around the high temperature pipe penetration of RCCV is limitted in the Technical Standard on Concrete Containments for Nuclear Power Plats(Draft) of Japan. This limit is the same as in ASME Sec.Ⅱ Div.2. Because strength of the concrete and other characteristics will change within the range of high temperature. Therefore, it is necessary to confirm that concrete temperature around the penetrations are bellow the temperature limits to assure the soundness of concrete. Objectives of the thermal loading tests of high temperature pipe penetration are as follows.

(3) To confirm the adequacy of the method of the calculation and boundary conditions for the temperature distribution analysis.
(4) To confirm that the temperature of concrete around the high temperature pipe penetration in actual plant is bellow the temperature limit of concrete during normal operation.

2. SHEAR TEST OF LINER ANCHOR

2.1 Test specimen and method

The test set-up of the liner anchor specimens is shown in Fig-1. Thickness of the liner plate is 6.4mm SGV49(JIS G3118), corresponding to ASME SA-516(1979) Gr.70, a medium carbon steel, and the liner anchors is tee-shaped, 75x75x6x9 and 100x100x6.5x10, SM 50. The liner plates are placed at both sides of all specimens, symmetrically about the centerline. Liner anchor sizes and the number of tee anchors are shown in Table-1. The spacing of anchors is 500mm in two anchor specimens. The concrete used for the test specimens has a maximum size aggregate of 25mm and an average slump of 8~10cm. The compressive strength of the concrete, poured under construction conditions, not typical laboratory conditions, is from 267kgf/cm^2 to 335kgf/cm^2 at 4 weeks.

A shear force is applied to the specimens by pulling the liner plates, and displacement of the liner anchors and stresses are measured. Furthermore, since maximum load is related to concrete cracking in some way, the cracks were observed at every step.

2.2 Results

Test results are summarized in Fig-2 through Fig-7.

(1) Maximum load

Maximum loads are different for one anchor specimens and two anchor specimens; with two anchor specimens producing lower loads. In case of the 75x75 tee, the maximum loads are in the range between 62tf to 71tf, while the displacements range from 2mm to 3mm in one anchor specimens (1-1 and 1-2). The maximum laods for two anchor specimens (2-1 and 2-2) range from 50tf to 65tf, while the displacements range from 0.6mm to 1.5mm. The maximum loads for the two anchor specimens are lower than those of one anchor specimens without regard to the size of liner anchor.

(2) Maximum displacement

Displacement of all specimens reaches about 5mm. As with loads, the maximum displacements of two anchor specimens are also lower than those of one anchor specimens.

(3) Cracks in concrete

Typical crack patterns around the liner anchor for one anchor and two anchor specimens are shown in Fig-2 and 3. Cracks around the first anchor in two anchor specimens are different from those in one anchor specimens.

- Slopes of the cracks behind the first anchor are gentle in the two anchor specimens, compared with those of the one anchor specimens.
- Cracks in front of the first anchor are longer than those of one anchor specimens.

Furthermore, it is characteristic in the two anchor specimens that cracks in the front of second anchor slope gently and extend to near the first anchor.

3. THERMAL LOADING TESTS OF HIGH TEMPERATURE PIPE PENETRATIONS

3.1 Test specimen and method

A test specimen of high temperature pipe penetration consists of inner process pipe, outer sleeve, anchor ring and gussets, and is anchored in RCCV. The size of the process pipe and sleeve is based on the penetrations which have been put into actual use, and the diameter of the process pipe and sleeve are 165mm and 508mm, respectively. The process pipe is covered by insulation. The length from the top of the sleeve to RCCV is 1200mm, based on the preliminary study of temperature distribution calculation to keep the ocncrete temperature limits. The model size is decided considering the range to have no effects on the temperature distribution.

A heater is installed inside the process pipe to make normal operating thermal conditions, and an environment box is set outside and inside of RCCV in order to control the temperature of inside of RCCV and R/B respectively. The test specimen and testing apparatus are shown in Fig-8.

3.2 Results

In this experiment, concrete temperature in the vicinity of penetration outside of RCCV was 62°C in maximum as shown in Fig-9. Analysis of temperature distribution, which simulate the experiment, was carried out and its results are shown in Fig-10. The test results and analysis results are relatively in good agreement in comparison with Fig-9 and 10. Therefore, it was confirmed that analysis method, including boundary conditions, of temperature distribution around penetration is reasonable.

To calculate the temperature distribution around the Main Steam (M/S) pipe penetration, whose temperature conditions are severest in high temperature penetrations of actual plant, the analysis model shown in Fig-11 was developed based on the analysis model which simulates the experiment. From the analysis result as shown in Fig-12, it was confirmed that concrete temperature around high temperature penetration is bellow 90°C, which is the limit of applicable temperature during normal operation of RCCV.

4. CONCLUSION

Results for the two anchor specimens indicate that the maximum load is lower and the stiffness in the initial, or elastic portion of the curve is higher than for the one anchor specimens. In considering this result, it is important to investigate cracking in concrete at maximum load. From investigation of the cracks, the maximum load of the two anchor specimens occures as the crack propagating from the second anchor's flange reaches the first anchor. If the strength of the anchor in shear can be defined as the combined compression and shear strength of the surrounding concrete, the first anchor's strength is supposed to be reduced since its upward restraint by the second anchor is weekened by the crack extending from the second to first anchor. It can be said that the maximum load of the first anchor is affected by the cracks from the rear anchor and is consequently lower than that of one anchor specimens. Therefore, idealized load-deflection curve for design of liner anchors will be set considering primarily the results of the two anchor specimens, to be conservative.

From thermal loading tests of high temperature pipe penetration, it was confirmed that the method and boundary conditions of temperature analysis around high temperature penetration was adequate by comparing test results and analysis results. Using these method and conditions, it was confirmed that concrete temperature around the M/S pipe penetration whose temperature is severest was estimated and bellow the temperature limit of concrete during normal operation.

5. ACKNOWLEDGEMENT

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6. REFERENCE

1) Saito,H., Kikuchi.R., Muramatu,Y., Hiramoto,M., Oyamada,O., Furukawa,H., Sasagawa,K., Ohmori,N., Suzuki,S., Sugita,M., Kobayashi,I., Yamaguchi,I. (1989). Experimental Study on RCCV of ABWR Plant Part 1; Outline of Research Study. Transaction of the 10th SMIRT Conference. Vol. J.

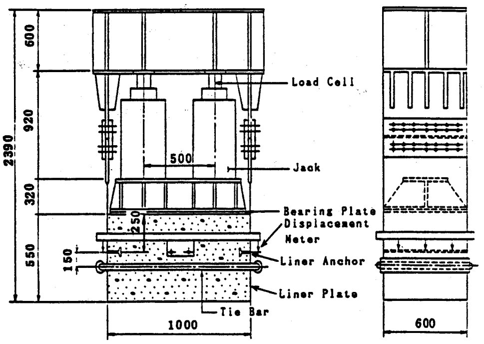


Fig-1 Test Set-up for One Anchor Specimen

Specimen		Anchor Size	No. of Anchor	Age (days)	Strength (kg/cm)	Young's Modulus (kg/cm)
1	1−1	CT75×75×6×9	1	39	275	2.21×10⁵
	1−2	CT75×75×6×9	1	61	276	(3.13×10⁵)
2	2−1	CT75×75×6×9	2	35	267	2.13×10⁵
	2−2	CT75×75×6×9	2	40	243	2.43×10⁵
3	3−1	CT100×100×6.5×10	1	38	335	2.46×10⁵
	3−2	CT100×100×6.5×10	1	41	276	2.87×10⁵
4	4−1	CT100×100×6.5×10	2	34	317	2.56×10⁵
	4−2	CT100×100×6.5×10	2	39	270	2.60×10⁵
5	5−1	L75×75×6×9	1	34	249	(3.42×10⁵)
	5−2	L75×75×6×9	1	36	253	2.18×10⁵

Table-1 Description of Specimens

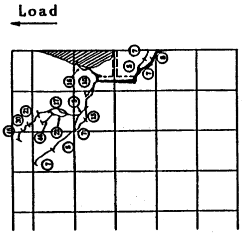


Fig-2
Crack Pattern of One Anchor Specimen

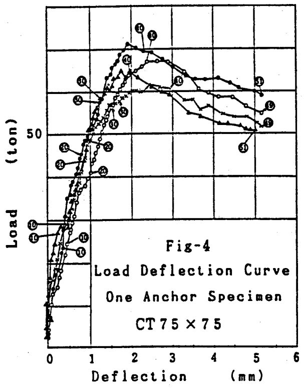


Fig-4
Load Deflection Curve
One Anchor Specimen
CT75×75

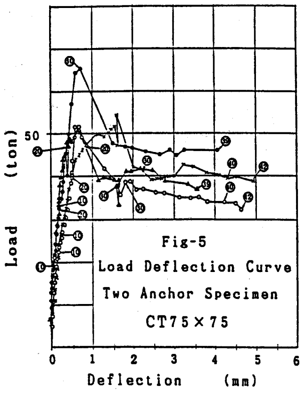


Fig-5
Load Deflection Curve
Two Anchor Specimen
CT75×75

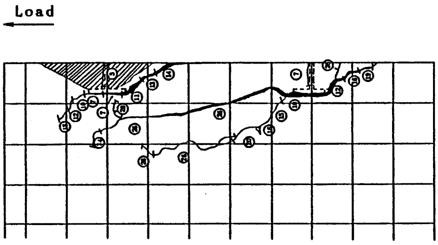


Fig-3
Crack Pattern of Two Anchor Specimen

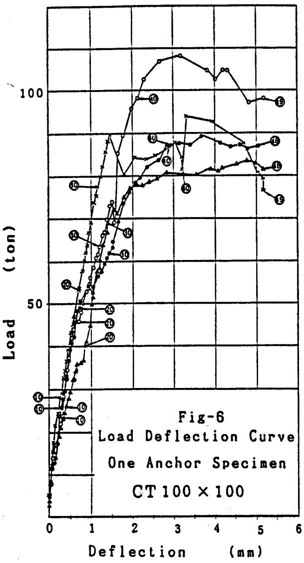


Fig-6
Load Deflection Curve
One Anchor Specimen
CT100×100

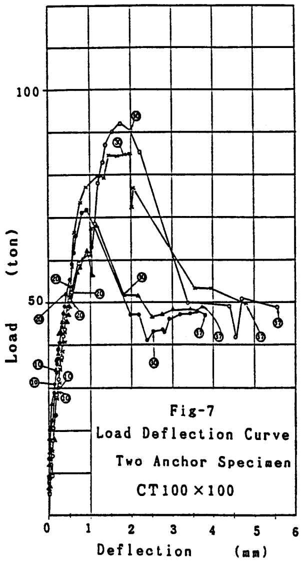


Fig-7
Load Deflection Curve
Two Anchor Specimen
CT100×100

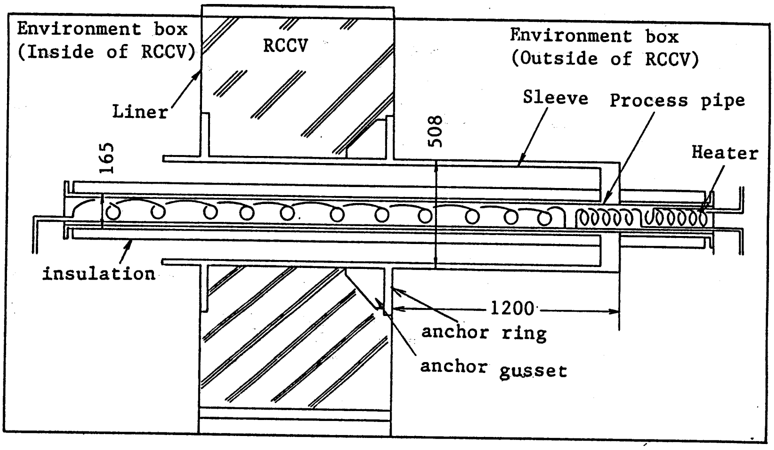
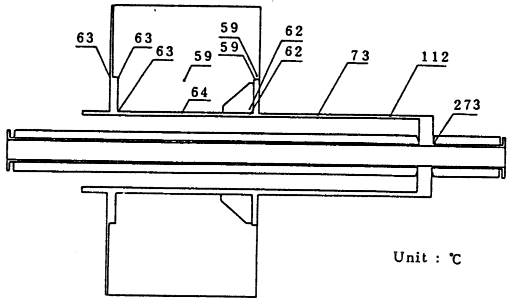


Fig-8 Testing apparatus and test specimen



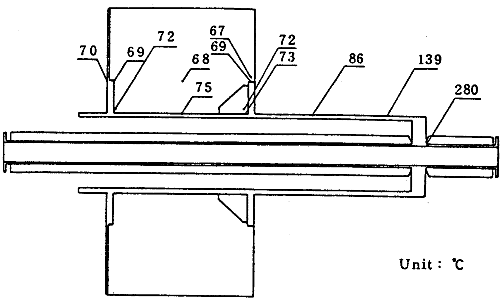
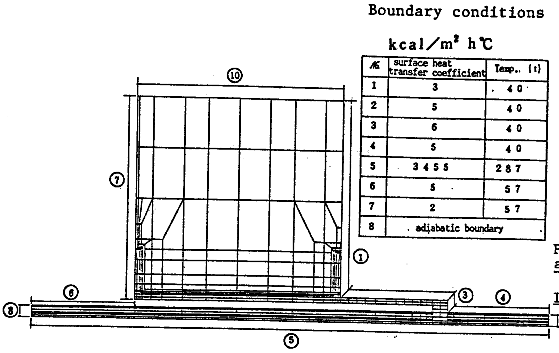


Fig-9 Test results of penetration temperature of test specimen

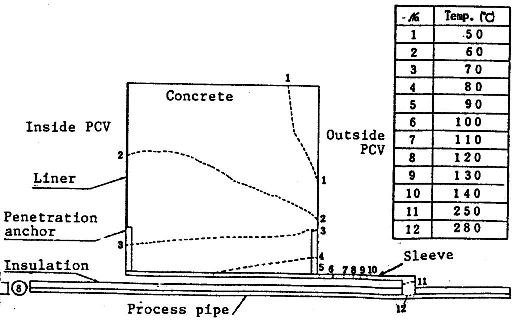
Fig-10 Calculation results of penetration temperature of test specimen



Boundary conditions

kcal/m² h℃

№	surface heat transfer coefficient	Temp.. (t)
1	3	40
2	5	40
3	6	40
4	5	40
5	3455	287
6	5	57
7	2	57
8	adiabatic boundary	



№	Temp. (℃)
1	50
2	60
3	70
4	80
5	90
6	100
7	110
8	120
9	130
10	140
11	250
12	280

Fig-11 Calculation model and conditions of M/S pipe penetration

Fig-12 Calculation results of M/S pipe penetration