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Summary of the Internal Pressure Capacity of Prestress Concrete Containment Vessel (PCCV)

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Abstract

Prestressed concrete containment vessel (PCCV) is the unique structures that are constantly exposed to harsh environmental conditions, acts as the final defensive shield against radiation leakage, and ensuring the structural safety of the dome is critical in nuclear power industry. Many related studied about the internal pressure capacity of PCCV are summarized in this paper.

Keywords: Ultimate internal pressure; Prestressed concrete containment vessel; Mechanical analysis, Failure mode; Finite element

Introduction

The nuclear containment acts as the final barrier against the release of radioactivity. Hence, its design, strict performance and safety evaluation under severe conditions are of great significance, whether through experiments or by numerical methods. In particular, the behavior prediction from functional to structural failure when the internal pressure is higher than the design pressure (Pd) is very important in terms of structural safety.

Experimental Work

On the one hand, much work has been done experimentally on the safety evaluation of prestressed concrete containment vessel (PCCV) subjected to internal pressure. A 1:4 scale PCCV model has been analyzed by the U.S. nuclear regulatory commission (NRC) and the nuclear power engineering cooperation (NUPEC) of Japan, and it is found that the limit state is firstly detected at 2.5Pd and the final torn failure is at 3.3Pd [1]. Another test in India shows that the crack firstly appears when pressured up to 1.56Pd [2]. In addition, a 1:10 scale model was tested in China and the final failure is at 2.7Pd with cylinder tendons fractured [3]. Rizkalla [4] tested a 1:14 scale model of PCCV, and the structure displays considerable ductility before hoop tendons reaching tearing failure at the mid-height of the cylinder.

Finite Element Analysis

On the other hand, various finite element analyses of PCCV have also been reported. Yonezawa et al. [5] established a finite model and predicted the ultimate capacity pressure to be 3.97Pd and the tendons torn at the mid-height of the wall. While Basha et al. [6] predicted it is in a range of 2.95-3.15Pd and the failure is at the local liner of the equipment hatch opening. Prinja et al. [7,8] found that the containment finally fails as the extensive concrete crack at the mid-height of the cylinder. Lee [9] found the crack occurs in all parts of the containment. Kwak & Kim [10] proposed a modified stress-strain relationship to simulate the post-cracking behavior, and results indicate the structure fails at the mid-height under 3.3Pd. Whereas, another numerical simulation suggests a final failure of vertical crack near the buttress [11]. While Zhou Z [12] found that the hoop tendons near the equipment hatch have yielded and the corresponding concrete has reached the ultimate tension strain.

Results of Hu [13] show that there are extensive cracks at the dome apex, the ring beam and the cylinder bottom, and the corresponding failure pressure is 1.86Pd. Other researches [14,15] simulated the over-pressurization of the 1:4 mode experimentally tested by NRC/NUPEC previously, and the numerical results are consistent with the experiment. Besides, another report shows that the liner integrity has significant effects on the loss of confinement, because the concrete failure appears quite early [16]. Xia et al. [17] sponsored a round robin analysis and predicted that the failure capacity is all above 2.5Pd. Zhang [18] developed an integral constitutive model to study the ultimate internal pressure, and the result is 3.04Pd.

Table 1: Summary and comparison of related research results.

References	Tendon Yielding		Extensive Concrete Cracking		Liner Tear	
	Pressure /Pd	Location	Pressure /Pd	Location	Pressure /Pd	Location
[19,17]	-	-	2.5	A	3.05	A
[20]	>2.5	-	2	B	-	-

[21]	>3.35	-	3.35	A	-	-
[5]	3.97	A	-	-	-	-
[6]	-	-	-	-	2.95-3.15	B
[1,22]*	-	-	2.5	A	3.3	B
[7,8]	3.6	A	-	-	2.5	B
[9]	-	-	2.92	A	-	-
[10]	3.3	A	-	-	-	-
[11]	2.78	A	-	-	-	-
[3]*	2.7	A	-	-	-	-
[23]	2.86	A	>2.86	-	-	-
[24]	>2.91	-	-	-	2.91	C
[12]	2.69	B	1.98	B	>3.0	-
[15]	3.87	A	-	-	-	-
[13]	-	-	1.86	C, D, E	-	-
[25]	>2.2	-	1.75	B	2.2	B
[18]					3.04	A
ANL#	3.15	A	-	-	2.56	A
AECL#	-	-	-	-	2.72	-
EDF#	4.9	-	-	-	-	-
Glasgow#	-	-	-	-	2.56-2.82	-
JAERI#	-	-	-	-	3.08	D
JAPC#	3.64	A	-	-	2.46	A
KINS#	3.51	-	-	-	-	-
HSE/NNC#	4.49	-	-	-	-	-
NUPEC#	4.03	-	-	-	2.62	-
IBRAE#	3.21	-	-	-	2.95	-
PRINCIPIA#	3.33	-	-	-	-	-
RINSC#	3.85	-	-	-	-	-
SNL/ANATECH#	3.38	B	-	-	-	-

A: Cylinder mid-height; B: Equipment hatch; C: Ring beam region; D: Dome; E: Cylinder bottom.

#: Cite the reference [26].

*: Experimental test. Other predictions used finite element codes.

For clearly reflect the results of related researches about the ultimate pressure and failure mode, a summary was shown in Table 1 [19-26].

Conclusion

This paper reviewed the studied on internal pressure of prestress concrete containment vessel and discussed the failure mode and ultimate capacity.

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