コンクリート工学年次論文報告集, Vol.16, No.2, 1994

論 文

[2016] Simplified Nonlinear Analyses of Reinforced Concrete Hollow Cylinders by Modelling into Shear Walls

Taweep CHAISOMPHOB*1, Yukio AOYAGI*2 and Zou YI*3

1. INTRODUCTION

In the conventional analysis of reinforced concrete (RC) hollow cylinders applied to containments for nuclear power reactors, storage tanks for liquefied natural gas (LNG), etc., rather complicated analysis method involving nonlinear effects of three-dimensional reinforced concrete shell elements are required. Practical application of this analysis to real structures is severely constrained by a huge amount of computational time. Hence, more simplified analysis might be needed for an application to a practical design of such structures. From one of previous efforts to establish the simplified analysis of RC hollow cylinders [1], it was reported that under horizontal loading, a stiffness of the hollow cylinder can be divided into two zones: a radial stiffness zone and a tangential stiffness zone. Based on this idea, it is possible to model a 3-dimension problem of the hollow cylinder into a 2-dimension problem of a shear wall.

This paper presents a simplified nonlinear analysis of reinforced concrete hollow cylinders under a monotonic horizontal loading. The concept of the proposed simplified analysis is to model a hollow cylinder into a shear wall consisting of a web wall resisting an in-plane shear force and flanges resisting a bending moment. In order to show a validity of the proposed shear wall model, the results of nonlinear analyses of the shear wall model by using a nonlinear finite element program for a RC panel structures called "WCOMR" [3] are compared with the experimental results of a model of the hollow cylindrical structure [2].

2. BASIC CONCEPTS OF MODELLING

Previous study on the mechanical behavior of nuclear containment structures under earthquake loading based on both experiments and finite element analyses suggested that the assignment of stiffness can be divided into two zones as follows:[1]

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*1 Engineering(English)Program, Thammasat University, D.Eng., Member of JCI
*2 School of Civil Engineering, Asian Institute of Technology, D.Eng., Member of JCI
*3 School of Civil Engineering, Asian Institute of Technology, M.Eng.

- Zone 1 for a radial stiffness covers the segment 0~45 deg. and 135~180 deg. (Fig.1).
- Zone 2 for a tangential stiffness covers the 90 deg. segment centered about the neutral axis of bending from 45 to 135 deg. (Fig.1).

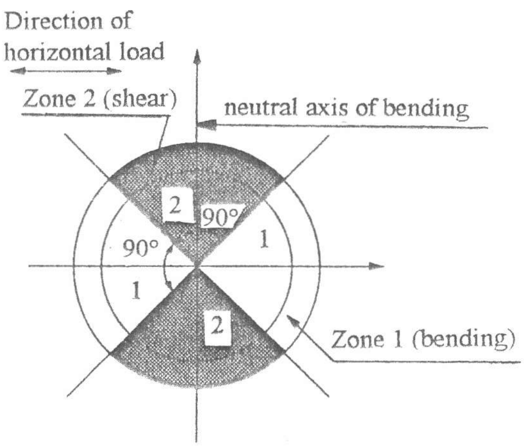


Fig. 1 Stiffness Assignments for Hollow Cylinders

Zone 1 and 2 are primarily associated with the bending and in-plane shear behavior, respectively. In other words, according to the distribution of stresses along a circumferential length of the cylinder, the concentration of bending stresses and that of in-plane shear stresses are mostly in zone 1 and zone 2, respectively [1]. Another reason for separating the zone 1 and 2 as shown in Fig. 1 is that in the range of elastic response the maximum in-plane shear stress of the hollow cylinder is twice the average shear stress which is a ratio between a horizontal force and a total cross-sectional area of the hollow cylinder. This means a half of the total cross-section is an equivalent one to resist an in-plane shear force, and hence the lines of 45 and 135 deg. are used to divide the zones.

This consideration provides a possibility to model a hollow cylinder into a shear wall. In this study, the same concept is adopted and is verified first by performing elastic analyses of the hollow cylinder subjected to a horizontal force at a top and checking the distribution of bending stresses and shear stresses along a circumferential length of the cylinder [4]. It is noted that a finite element program adopted for the present elastic analysis of the hollow cylinder is called "XFEAP" in which a reliable degenerated shell element is available [4].

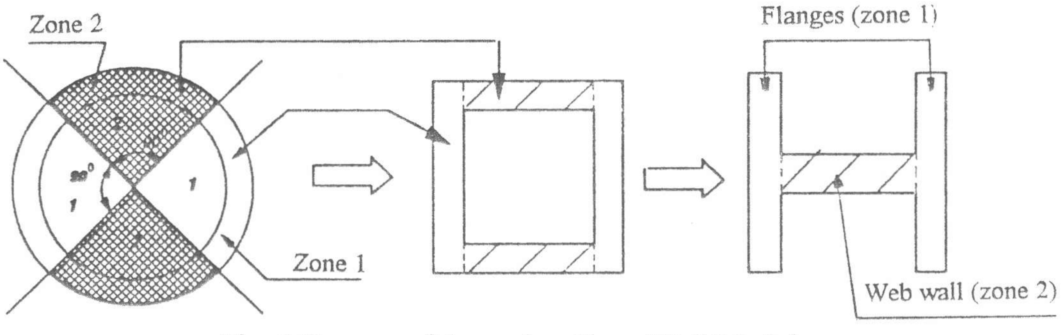


Fig. 2 Process of Assuming Shear Wall Models

By dividing the cross-section of a hollow cylinder into zone 1 and 2, and considering the extreme cross-sectional shapes that can resist bending for zone 1 and shear for zone 2, the most simplified model of the hollow cylinder might be a box-type shear wall as shown in Fig. 2. Furthermore, without losing generality, the box-type shear wall model is reduced into a H-type shear wall model (Fig. 2). In Ref.[4], the results of elastic analyses for the hollow cylinder and the H-type shear wall model by using the "XFEAP" program show that a difference of the horizontal displacement at the top of both structures is less than 1%. However, the differences of the maximum in-plane shear stresses and the maximum bending stresses are in the range of 10-15%. In spite of this discrepancy of the stresses, these results indicate that it is possible to make a good agreement between the displacement of the hollow cylinder and the shear wall model, and hence a verification of the shear wall model to simulate a global behaviour of the hollow cylinder in terms of a load-displacement response is made in an elastic range. The methods of determining cross-sectional dimensions of the shear wall are as follows :

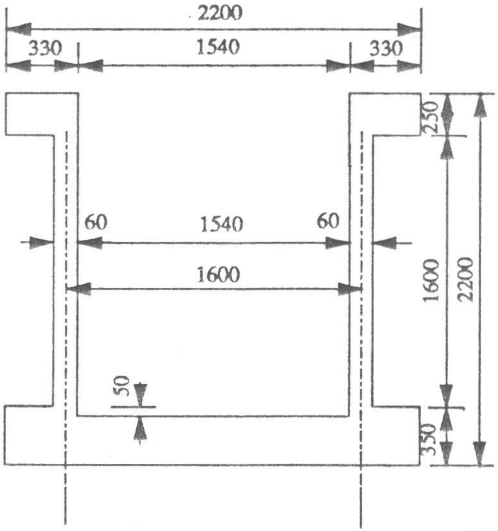
- Cross-sectional areas of zone 1 and 2 of the hollow cylinder as mentioned above are approximately equal to those of flanges and a web wall of the H-section of the shear wall model in Fig. 2, respectively.
- Almost the same thickness as the hollow cylinder is used for the flanges and the web wall.
- The same height as the hollow cylinder is used for the shear wall model.

It is noted that the material properties of both structures are the same.

3. NONLINEAR ANALYSES OF SHEAR WALL MODELS

3.1 TESTED HOLLOW CYLINDERS

A test of the hollow cylinder in Ref.[2] is selected to check a reliability of the proposed shear wall model. Dimension and material properties of the tested hollow cylinder are illustrated in Fig. 3. A cyclic horizontal force is applied at the top of the hollow cylinder. However, an envelope of the responses obtained from this test is used to compare with the results of the present static analysis.



Reinforcement ratios in the horizontal and vertical directions are equal to 0.018.

Material Properties

Concrete kgf/cm^2	compressive strength	316
	tensile strength	27.7
	elastic modulus	184000
Steel kgf/cm^2	yield strength	3900
	tensile strength	5410
	elastic modulus	1700000

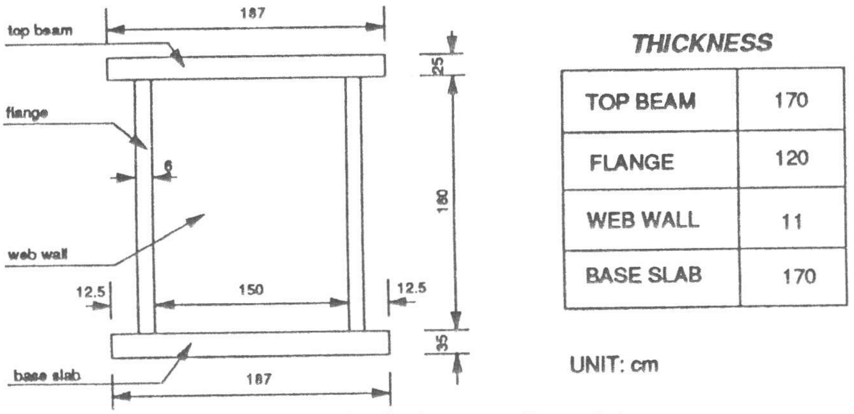
(UNIT: mm)

Fig. 3 Dimension and Material Properties of the Tested Hollow Cylinder

3.2 ASSUMED SHEAR WALL MODELS

Based on the H-type shear wall model in Fig. 2, the tested hollow cylinder is modelled into the shear wall as shown in Fig. 4. For the material properties, the same values as in Fig. 3

are used. It is noted that the adoption of the dimensions of the shear wall model in Fig. 4 with the same material properties as the cylinder is obtained from the results of elastic analyses as discussed in 2. In other words, the assumed shear wall model with these dimensions and material properties can give a good agreement of elastic responses compared with those of the hollow cylinder [4].



THICKNESS

TOP BEAM	170
FLANGE	120
WEB WALL	11
BASE SLAB	170

Fig. 4 Assumed Shear Wall Models

3.3 ANALYTICAL PROCEDURES

In this study, a nonlinear finite element program for a RC panel structures called "WCOMR" is selected due to its reliable constitutive models of 2-dimensional RC materials [3]. As shown in Fig. 5, the assumed shear wall model is discretized by using 4-node panel elements for flanges, a web wall, a top beam and a base slab, and joint elements for a connection between two panel elements of different stiffnesses. It is noted that the top beam and the base slab are treated as rigid parts. A horizontal force is applied at the top, and a boundary condition is fixed at the base. By increasing values of the horizontal force monotonically, nonlinear load-displacement curves of the shear wall are obtained through the usual iteration procedure.

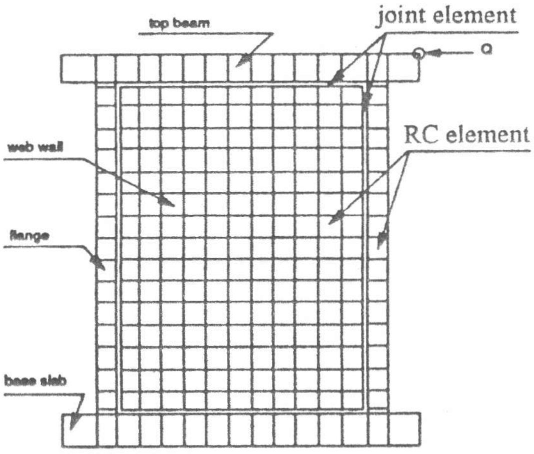


Fig. 5 Discretization of the Shear Wall

4. DISCUSSION OF ANALYTICAL RESULTS

By performing nonlinear analyses of the assumed shear wall in Fig. 4 and comparing the analytical results with the experimental results [2], it was found that for a comparison of the load-displacement relation, this assumed shear wall was much stiffer than the hollow cylinder, and a difference of the two results was not acceptable [4]. This indicates that due to the effects of material nonlinearities of RC on the behaviour of the assumed shear wall, the shear wall model used to simulate a linear behaviour of the hollow cylinder is not necessarily the same as that used to simulate a nonlinear behaviour. While keeping material properties to be the same as the hollow cylinder, modifications of dimensions of the assumed shear wall are made in order to simulate the nonlinear behaviour of the hollow cylinder. The main dimensions of the shear wall considered in the present parametric studies are a width, a thickness and a reinforcement ratio of the flanges and the web wall, and details are given in Ref.[4]. The most suitable shear wall model is obtained by the following changes of the dimensions of the model in Fig. 4 as

- Web wall : thickness is changed from 11cm to 8.15cm (74%), width from 150cm to 130cm (87%), reinforcement ratio from 0.018 to 0.0138(77%).
- Flange : reinforcement ratio is changed from 0.018 to 0.016(89%).

It is noted that the cross-sectional area of the zone 2 of the hollow cylinder (a 90 deg. segment about the neutral axis of bending) is less than that of the above web wall due to a decrease of the thickness and the width of the web wall, and the reinforcement ratios of both web wall and flanges are less than that of hollow cylinder. To establish the method of determining the dimensions of the assumed shear wall needs further investigations.

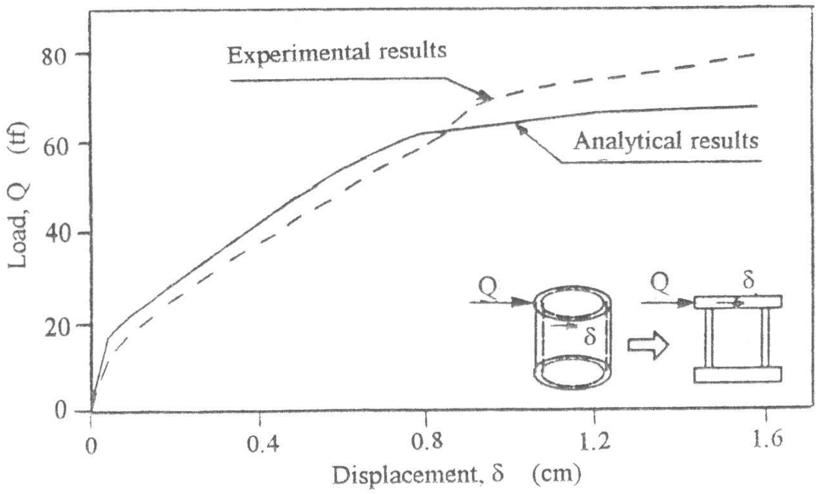


Fig. 6 Comparison of Load-Displacement Relations

Analytical results by using the most suitable shear wall model are compared with the experimental results in Fig. 6 for the relation between a load and displacement at top, and in Fig. 7 for the relation between a load and a vertical rebar strain in the zone 2. From these figures, it can be seen that a reasonably good agreement of the load-displacement relation can be obtained, and after yielding of rebars the shear wall seems to be softer than the hollow cylinder. However, there exists a difference of the load-rebar strain relation even before yielding. Hence, it might be concluded that there is a possibility to simulate the nonlinear global behaviour of the hollow cylinder in terms of the load-displacement response.

5. CONCLUDING REMARKS

This study is a preliminary attempt to simplify the complicated analysis of a reinforced concrete hollow cylinder subjected to a monotonic horizontal loading. The basic concept of this simplification is to use a shear wall model, i.e., to reduce a three-dimensional nonlinear problem to a two-dimensional one. By dividing a section of hollow cylinder into two zones : zone 1 for resisting the bending effect and zone 2 for resisting the in-plane shear effect, the model of H-section of the assumed shear wall consisting of flanges for zone 1 and a web wall for zone 2 is proposed. By using this assumed shear wall, nonlinear analyses are performed to simulate the behaviour of the tested hollow cylinder subjected to a horizontal force. From the parametric studies on the effects of dimensions of the shear wall, it was found that there was a possibility to apply the assumed shear wall for simulating nonlinear load-displacement behaviour of the hollow cylinder. However, in order to find the general rules to determine the dimensions of the assumed shear wall, more investigations are needed.

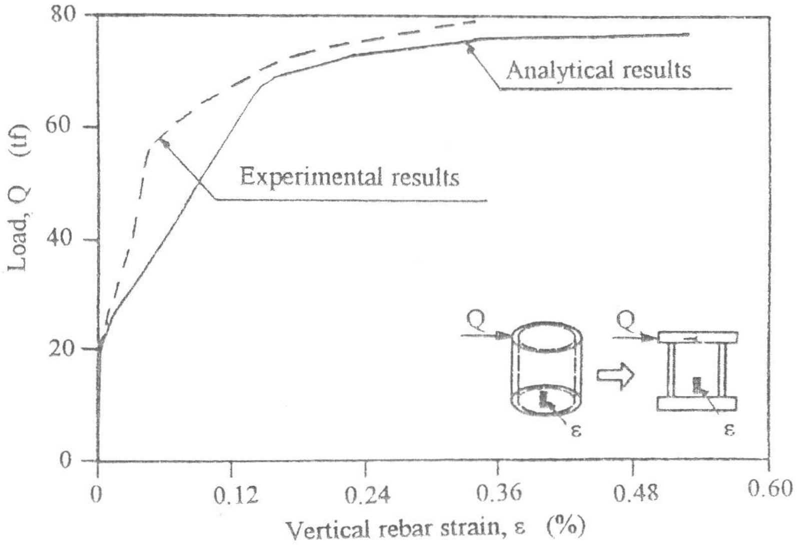


Fig. 7 Comparison of Load-Rebar Strain Relations (in Zone 2)

ACKNOWLEDGMENT

The authors express their deepest appreciation to Dr. K. Maekawa, Associate Professor of University of Tokyo for his helpful suggestion and kind cooperation.

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