

Out-of-Plane Wall Behavior in Seismic Analysis of Rectangular Reinforced Concrete Containment Structures

S. Aihara, K. Atsumi, K. Ujiie, K. Emori, H. Shimizu, H. Yokozawa
Kajima Corporation, 1-1, 2, Nishi-Shinjuku, Shinjuku-ku, Tokyo 160, Japan

Abstract

The objective of this paper is to present the out-of-plane vibrational behavior of flange walls of R/C box type containment structures. The structure to be studied is composed of two portions, the upper portion which is the box substructure of 64 m in length by 64 m in width by 30 m in height, and the lower portion which is the stiff substructure with plenty of walls placed inside, of 110 m in length by 110 m in width by 49 m in height including thick mat foundation.

Dynamic behavior of this structure is investigated by two types of models. One is the well known single stick lumped mass model. The other is the gridwork lumped mass model. In the gridwork lumped mass model, the web wall of the box substructure is modeled to be lumped mass system, whereas the flange wall of it is modeled by a uniform gridwork which consists of mutually orthogonal members rigidly connected at the intersections. The gridwork members are evaluated in order that the stiffness of the gridwork structure is similar to that of an orthotropic wall plate. Responses under strong earthquake motions are obtained by numerically integrating the equations of motion in a step by step procedure.

For the cases considered, the response results between the single stick lumped mass model and the web wall portion of the gridwork lumped mass model are generally in good agreement, whereas the response results of the flange wall portion of the gridwork lumped mass model show large local amplification as the out-of-plane vibrational behavior. The single stick lumped mass model can not reveal this type of phenomenon.

It can be concluded that when designing R/C huge box type structures for earthquake resistance, much attention should be made on the out-of-plane vibrational behavior of flange walls of the structures.

1. Introduction

This paper provides dynamic analysis for a rectangular reinforced concrete containment structure and its vibrational behavior. The structural preliminary design work of this structure had been performed in accordance with the design criteria, codes and standards as required under current nuclear plant licensing regulations in Japan. [1, 2] Preliminary sizes, thicknesses of structures and structural elements were determined by the loads combined in a manner consistent with MITI (Ministry of International Trade and Industry of Japan) Concrete Containment Vessel Codes Revision in 1979. [2] Critical load combinations for the preliminary design were conditions of normal operation, the maximum design earthquake (S_1 earthquake) and thermal load at normal operation. The thickness of walls were determined by the S_1 earthquake load with limit of shear stress of $F_c/10$ where F_c is the concrete strength.

The objective of this study is to investigate the out-of-plane vibrational behavior of flange walls of the rectangular reinforced concrete containment structure. Horizontal earthquakes are considered to investigate overall dynamic behavior of the structure. A part of huge walls in the upper part of the structure will be excited into vibration by the motion of the structure. Vibrational analyses are made on a digital computer with the parts of the wall included as an additional lumped mass in the system.

2. Building Description

The rectangular reinforced concrete containment structure selected for study is shown in Figure 1. It consists of three structures: a rectangular containment structure, an internal structure and a surrounding structure. It is structurally designed to behave as a single structure.

The structure is composed of two portions, the upper portion and the lower portion. The upper portion is the rectangular reinforced concrete box structure, 64 m in length by 64 m in width by 30 m in height. The lower portion is the stiff structure with plenty of walls placed inside, 110 m in length by 110 m in width by 49 m in height including thick mat foundation of 6 m thickness. An opening of 15 m in height by 20 m in width exists in the box containment structural wall over the operating floor level.

The roof truss rests on top of the rectangular reinforced concrete containment structure. 0.5 m thick reinforced concrete roof slab which is a ceiling of the containment structure is supported by this roof truss. Roof truss with reinforced concrete slab is vertically flexible, horizontally stiff, relative to the supporting walls. Inside surfaces of the containment: the ceiling, walls and base slab, are lined with a leak tight liner plate. The containment structure is connected to the internal structure through embedded plates at slabs and walls of the internal structure. The containment structure is enclosed by a leak-resistant confinement steel structure.

The common and large basemat system is adopted to reduce uplift during a seismic event. A 6 meter thick reinforced concrete foundation is assumed in this study. This thickness is typical of foundations used on nuclear power plants in Japan. Key dimensions of the rectangular containment structure are also shown in Figure 1.

3. Models for Seismic Analysis

Dynamic behavior of this structure is investigated by two types of models.

One is the well known single stick lumped mass model. It is because an internal structure and a surrounding structure are assumed to be attached to the containment structure. This is shown in Figure 1. The other is the gridwork lumped mass model. The web wall of the box substructure which is horizontally stiff relative to the flange wall, is modeled to be a lumped mass system, whereas the flange wall of it is modeled by a uniform gridwork which consists of mutually orthogonal members rigidly connected at the intersections. The gridwork members are evaluated in order that the stiffness is similar to that of an orthotropic wall plate. The mass of the flange is assumed to be concentrated at the nodes of the gridwork. Torsional resistance of the components of the gridwork is neglected. Shear deformations and flexural deformations of constituent members are taken into account.

In order to investigate the out-of-plane vibrational behavior of flange walls with large opening, the gridwork lumped mass model is also adopted. The gridwork lumped mass in the opening portion is eliminated. The gridwork lumped mass model with opening is shown in Figure 2. The gridwork lumped mass model is a better representation for taking into account the flange wall jogs. The weights of the masses and the section properties of the members are computed from the building geometry and material properties. The soil is modeled as a rocking spring and as a sway spring. Sway spring is the shear spring at the bottom of the base mat. Rocking spring is the rotational spring under the base mat.

4. Seismic Analytical Conditions

Two earthquake acceleration records are used to represent the specified ground motion. Seismic analytical conditions are summarized below.

- o Seismology Earthquakes El Centro 1940 NS, and Taft 1952 EW
Horizontal Ground Acceleration 0.30g OBE
- o Concrete Young Modulus $2.1 \times 10^5 \text{ kg/cm}^2$
Poisson's Ratio 0.187
- o Soil Hard Soil Unit Weight 2.5 g/cm^3
Shear Wave $V_s = 1300 \text{ m/sec}$
Poisson's Ratio 0.345
- o Spring Constant of Soil
Sway Spring $K_s = K_h A = 2.00 \times 10^8 \text{ t/m}$
Rocking Spring $K_R = K_v I = 5.29 \times 10^{11} \text{ tm/rad}$
where $K_h = 18 \text{ kg/cm}^3$, $K_v = 24 \text{ kg/cm}^3$
 $A = \text{Area of base mat}$
 $I = \text{Moment of inertia of base mat}$
- o Damping Factor Concrete Containment Structure 5 %
Sway and Rocking Spring 5 %
- o Computation Time 8 sec.
- o Time Increment 0.02 sec.

Response under strong earthquake motions, such as El Centro 1940 NS and Taft 1952 EW of 300 gal, are obtained by numerically integrating the equations of motion in a step by step procedure. Rayleigh type damping is used in this study. Soil spring constants are calculated in a same manner as shown above.

The computer program NUPP-II is chosen for this elastic dynamic analysis. This program which is developed by Kajima Corporation, is applicable to the two-dimensional structural system of arbitrary configurations.

5. Computed Results and Conclusions

Free vibration modes, periods and participation factors of three models are shown in Table 1. The fundamental period of each model is in the range of 0.24 - 0.26 sec. The single stick lumped mass model has the shortest fundamental period and the gridwork lumped mass model with opening has the longest fundamental period in the three model. Free vibration modes of the gridwork lumped mass model with opening are shown in Figure 3. Local amplification of the flange wall in the free vibration modes is significant.

Computed response values of flange walls: maximum accelerations, displacements, shearing forces and overturning moments, of the gridwork lumped mass model are shown in Figure 4 for without opening and shown in Figure 5 for with opening, respectively. [4] Comparison are made among response values of three models. For the cases considered, the response results between the single stick lumped mass model and the web wall portion of the gridwork lumped mass model are generally in good agreement, whereas the response results of the flange wall portion of the gridwork lumped mass model show large amplification as the out-of-plane vibrational behavior, compared to those of the single stick lumped mass model. The single stick lumped mass model can not reveal this type of phenomenon. Table 2 indicates that compared to the response values of acceleration and displacement at level 10 or 11 in the single stick lumped mass model, those in the gridwork lumped mass model vary 1.7 to 2.3 times larger values for the flange wall without opening and vary 4.5 to 7.1 times larger values for the flange wall with opening, respectively. The results with the single stick lumped mass model indicate that the overall maximum shearing forces and the maximum overturning moments are conservative. [3] The influence of opening is prominent as the out-of-plane vibrational behavior of flange walls. Transverse shear reinforcements are needed for the flange walls especially at the operation floor level. The walls of box substructure should be stiffened to reduce those local deformations.

It can be concluded that when designing reinforced concrete huge box type structures for earthquake resistance, much attention should be made on the out-of-plane vibrational behavior of flange walls of the structures. Further studies are considered necessary in order to develop a conceptual structural plant design for the rectangular reinforced concrete containment structure.

References

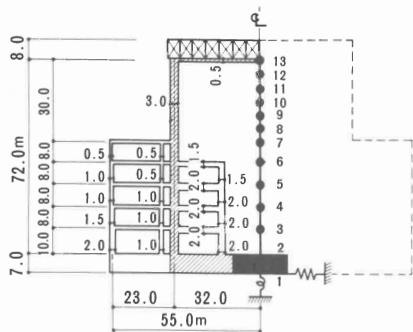
1. Architectural Institute of Japan Standard for Structural Calculation of Reinforced Concrete Structures, AIJ, Japan, 1975.
2. MITI CCV Codes, MITI Revision, Japan, 1979.
3. P. R. Perumalswami, and J. S. Dalal, "Modeling of Slabs in Seismic Analysis of Nuclear Power Plant Buildings," Nuclear Engineering and Design, 47, 1978.
4. K. Ujiie, K. Emori and H. Yokozawa, "Out-of-Plane Vibrational Behavior of R/C Box Type Containment Structures," Proc. of the 2nd Symposium on the Use of Computers in Building Engineering, Tokyo, Japan, March, 1980.

Table 1 Free Vibration Modes

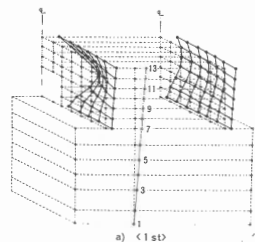
Modes	Gridwork Lumped Mass Model With Opening		Gridwork Lumped Mass Model Without Opening		Single Stick Lumped Mass Model	
	Period (sec.)	β	Period (sec.)	β	Period (sec.)	β
1	0.260	-6.806	0.257	-3.218	0.246	-1.939
2	0.202	-8.326	0.166	-3.466	0.117	-1.476
3	0.164	4.038	0.119	1.533	0.079	-0.212
4	0.124	-2.169	0.092	1.648	0.071	0.537
5	0.094	-2.221	0.084	-1.907	0.052	0.319
6	0.091	-1.329	0.076	0.136	0.040	0.167
7	0.084	-2.730	0.064	-0.993	0.034	-0.075

Table 2 Comparison of Response Values (Gridwork Lumped Mass Model)
(Single Stick Lumped Mass Model)

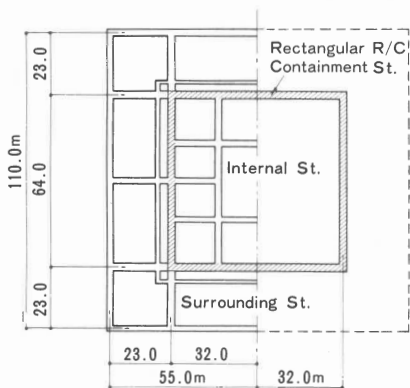
Level		(Level 11) Wall W/O Opening		(Level 10) Wall W/Opening
		W/O Opening Model	W/ Opening Model	W/ Opening Model
Max. Acc.	El Centro	1.74	1.60	4.64
	Taft	2.23	2.30	7.07
Max. Acc.	El Centro	1.86	1.69	4.58
	Taft	2.14	1.95	6.45



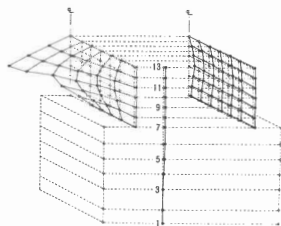
(a) Section



a) < 1st

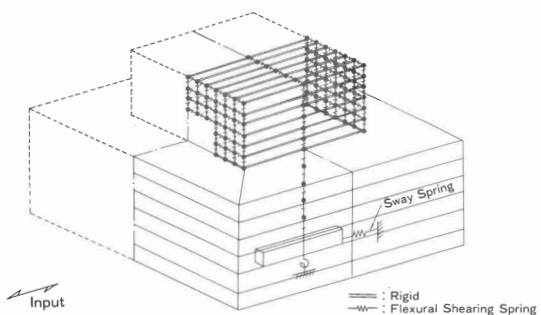


(b) Plan



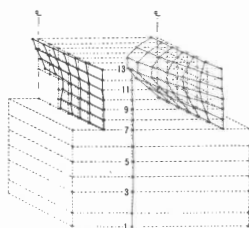
b) < 2nd

Fig. 1 Idealized Rectangular Containment Structure



Gridwork Lumped Mass Model

Fig. 2 Gridwork Lumped Mass Model with Opening



c) < 3rd

Fig. 3 Free Vibration Modes

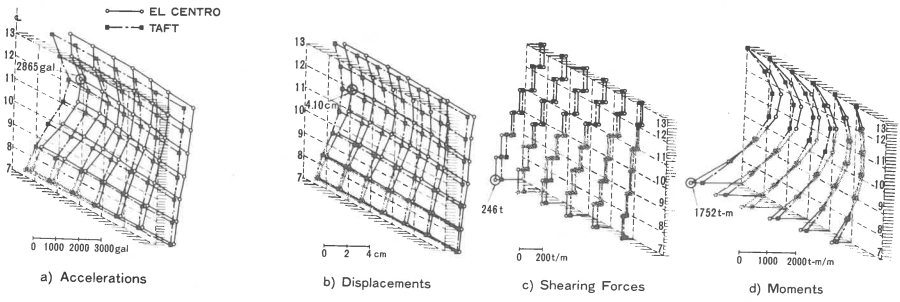


Fig. 4 Max. Response Values for without Opening

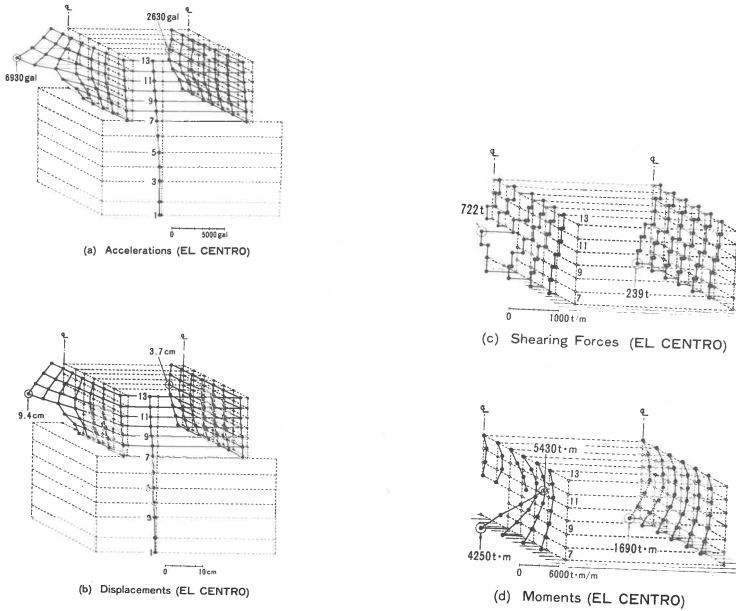
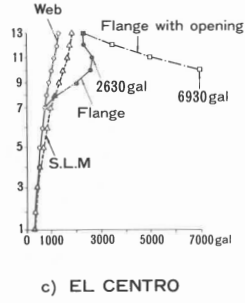
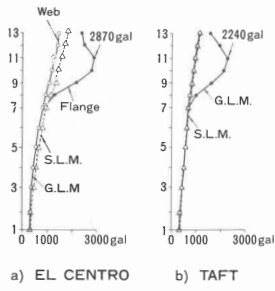
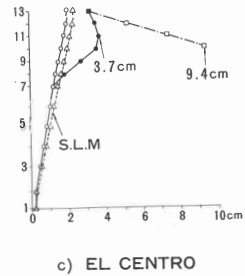
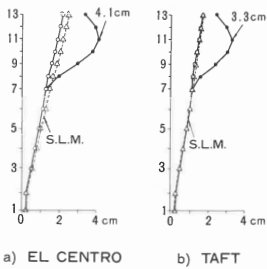


Fig. 5 Max. Response Values for with Opening

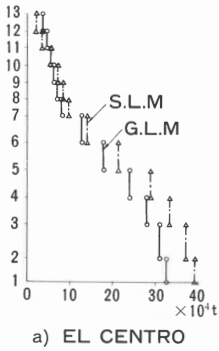


Max. Accelerations (gal)

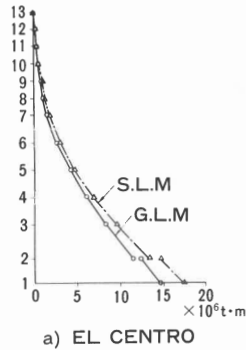


Max. Displacements (cm)

S.L.M = Single Lumped Mass Model
G.L.M = Gridwork Lumped Mass Model



Max. Shearing Forces



Max. Overturning Moments

Fig. 6 Comparison of Max. Response Values