Experimental Study on Concrete Shear Wall Behavior under Seismic Loading

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ABSTRACT

An experimental program has been undertaken on the dynamic behavior of shear walls with and without openings. The experimental set-up, the test program and the main results will be detailed in the paper.

1 INTRODUCTION

Shear walls are very important for the dynamic behavior of reprocessing plant buildings. So, in order to study their ultimate behavior under dynamic loading, an experimental program was undertaken.

Thirteen walls, with and without openings, were tested up to collapse and various frequencies of the input force were applied.

The experimental set-up and the main results of the tests are described in the following sections.

2 EXPERIMENTAL SET-UP

2.1 Description of the walls

The concrete squat shear walls which were tested have the following characteristics: height 0.375 m, width 0.75 m, thickness 0.05 m. The walls are linked to two thick horizontal beams (Fig. 1). The lower one is fixed firmly to the floor. A mass, equal to 1.25 tons, is added to the upper beam and gives a compression stress equal to 0.4 MPa. The gravity center of the mass is 0.15 m above the wall. A guiding frame ensures a longitudinal motion of the added mass (Fig. 2).

Thirteen walls were tested: seven without openings, three with a centered opening and three with a corner opening. The size of the opening is the third of the size of the wall.
The reinforcement consists of a welded lattice which leads to 0.28 % steel ratio. In addition, four bars, with a 6 mm diameter, are introduced on each side of the walls. In the same way around the openings, four bars are added.

2.2 Excitation

An actuator applies the dynamic loading to the added mass \( F = -M \dot{Y}_0 \) at the midheight of the top beam.

The first wall was tested under static loading in order to verify that there is no scale effect. This is important for the comparison of these dynamic tests to previous static tests performed in CEBTP Laboratory on scale two walls (Bouchon and al. 1989).

A sinusoidal force with a linearly increasing envelope was applied to the twelve other walls. The frequencies of the forces were equal to \( f_0/2 \), \( f_0 \) and \( 2f_0 \) and are given in Table 1 (\( f_0 \) being the estimated frequency of the cracked wall, that is to say calculated with the Young modulus associated to the concrete when there is fissuration).

As the walls without opening were tested firstly, some of the tests were repeated, in terms of force frequency, but slight changes were brought to the boundary conditions such as introduction of stops at the lower beam base.

Calculations with the method described in Wang and al. 1989 ; Wang 1990, were performed before the dynamic test in order to define the time variation of the force envelope. The objective, which was the collapse of the wall in fifteen cycles, commands the envelope gradient. In fact, during the test, the force was increased beyond these fifteen cycles condition up to the limits of the actuator. In addition, due to driving force difficulties, the applied force envelope was not exactly linear.

3 TEST PROGRAM

The test program for each wall includes :

- modal characterization before and after the dynamic test ;
- dynamic test up to collapse.

The mechanical characteristics of the concrete was measured for each wall the day of the dynamic test.

4 INSTRUMENTATION

The instrumentation is related to the measurement of the wall global behavior, so it is composed of force sensor and displacement sensor on the actuator, displacement sensors which measure the vertical and horizontal motion of the two lower and two higher corners of the walls, accelerometers which measure the vertical and horizontal motion of the mass. Temporary instrumentation was used for the modal characterization tests.
5 MODAL ANALYSIS

The frequencies and damping factors measured for the first mode are given in Table 2. Among these results, one can notice an important decrease of the frequency of the PJ03 wall compared with the others. This decrease observed for this first wall tested was related, after detailed examination, to an initial damage during the setting. This influence of non visible cracks on the stiffness of walls was already observed by other authors (Farrar 1989).

The second mode frequencies are greater than 150 Hz for all types of walls.

After the dynamic test, the resonance curve shape is strongly modified and one can no more define modes but only frequencies associated to wide peaks which are around 50 Hz.

6 DYNAMIC TESTS

The post test examination of the walls shows :
- for the walls without openings, cracks along the diagonals and for some tests damage at the lower corners. Usually, the behavior is non symmetric (see Fig. 3).
- for centered opening walls, cracks going from the angle of the opening to the corners of the wall (see Fig. 4).
- for the walls with opening in the corner, an important crack going from the corners of the opening to the upper corners of the wall (see Fig. 5).

In order to analyse in details the test results, the hysteretic loops were calculated from the applied force, $F_n$, the inertial force associated to the mass motion, $M \ddot{\gamma}$, and the mass displacement $\dot{\gamma}$. An example of such loops, for a wall with centered opening, is given in Figure 6.

From these curves, the stiffness of each cycle ($K = (P-M\ddot{\gamma})/D$) as a function of the displacement was calculated ; it leads to the following comments :
- the stiffness decreases when the amplitude of the motion increases (Fig. 7 and 8) as was noticed in Kaneally and Burns 1986.
- while the stiffness of PJ03 is smaller for low displacement than the stiffness of the other walls, its stiffness for higher amplitude is similar to that of the other walls. We could say that the wall has no memory of its initial state at high deformation level.
- the difference between the stiffness of the wall with centered opening and the stiffness of the wall with corner opening is small, especially during the phase of steel yielding.
- the walls without opening are stiffer than the walls with opening especially for low excitation level.

Each loop area was also calculated in order to define an equivalent damping. This damping was increasing up to 10 % for
all types of walls, then it remains constant except for few tests where an increase up to 30% was observed without up to now explanation of this phenomena.

7 CONCLUSIONS

Experimental dynamic behavior of shear walls under various frequencies of the input acceleration was studied. The test results analyses have given, in addition to the time history of the motion, the stiffness as a function of the displacement and the envelope of the cyclic loops. All these results are basic data for the validation of theoretical models.

REFERENCES


Keneally, R., Burns, J. (1986). Experimental investigation into the seismic behavior of nuclear power plant shear wall structure. Symposium on current issues related to nuclear power plant structures equipment and piping - Raleigh N.C.

Figure 1 - View of the shear wall with centered opening(unit = mm)
Figure 2 - Experiment set-up

Figure 3 - Wall without opening

Figure 4 - Wall with centered opening

Figure 5 - Wall with opening in a corner

Figure 6 - Hysteretic loops of a wall with centered opening (excitation frequency = 10 Hz)
STIFFNESS OF THE WALLS
WITHOUT OPENING

STIFFNESS OF THE WALLS
WITH OPENING

<table>
<thead>
<tr>
<th>Opening</th>
<th>No</th>
<th>Center</th>
<th>Corner</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall n°</td>
<td>3 1 2 4 11 12 13</td>
<td>5 6 7</td>
<td>8 9 10</td>
</tr>
<tr>
<td>Frequency (Hz)</td>
<td>0 13 13 26 40 13 26</td>
<td>10 20 30</td>
<td>10 20 30</td>
</tr>
</tbody>
</table>

- TABLE 1 -
Frequencies of the input force

<table>
<thead>
<tr>
<th>Opening</th>
<th>No</th>
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<tr>
<td>Wall n°</td>
<td>3 1 2 4 11 12 13</td>
<td>5 6 7</td>
<td>8 9 10</td>
</tr>
<tr>
<td>Frequency (Hz)</td>
<td>39 72 70 71 71 74 73</td>
<td>60 60 56 56 56 57</td>
<td></td>
</tr>
<tr>
<td>Damping (%)</td>
<td>1.8 0.5 0.6 0.6 0.5 0.6</td>
<td>0.6 0.5 0.9 0.5 0.3</td>
<td></td>
</tr>
</tbody>
</table>

- TABLE 2 -
Characteristics of the first mode