PROPOSALS FOR ASEISMIC DESIGN METHOD ON NONSTRUCTURAL ELEMENTS

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SUMMARY

This paper presents some proposals for aseismic design method of non-structural elements based on several experiments and field surveys. The results of experiments on various kind of exterior walls and partitions are also explained. We will also discuss field surveys after an earthquake concerning the fall of broken glass. The proposals deal with not only architectural detailing but also environmental design.

INTRODUCTION

Nonstructural elements such as exterior walls, partitions and openings have been severely damaged by recent earthquakes in Japan. There have been many efforts made to establish aseismic design methods of nonstructural elements. The authors have participated in these efforts and made some proposals based on investigations of earthquake damges and of experiments on seismic behavior of nonstructural elements. In this paper, the authors will introduce the major activities in this field in Japan as well as our research and proposals.

EARTHQUAKE DAMAGES AND RESEARCH ACTIVITIES

Earthquake Damages

In the Niigata earthquake (1964), reinforced concrete buildings were tilted due to soil liquifaction. In the '68 Tokachi-oki earthquake (1968) reinforced concrete buildings were severely damaged. On the other hand, damages to nonstructural elements did not appear so critical. In 1978, three major earthquakes occurred in Japan. The Near Izu-Ohshima earthquake (Jan., 1978) severely damaged nonstructural elements such as exterior walls, for instance, mortar finishes on wooden dwellings. The first Off-Miyagi prefecture earthquake (Feb., 1978) resulted in much glass breakage. The second Off-Miyagi prefecture earthquake (June, 1978) greatly damaged building structures as well as nonstructural elements. Several units of a precast concrete curtain wall in a three storied steel structure fell down. Autoclaved Light-weight concrete (ALC) panels were also severely damaged and some of them fell down out of the exterior walls. The Mid-Japan Sea earthquake (1983) also resulted in a lot of glass breakage.

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Research Works

During the development of aseismic design method of super high-rize buildings in Japan, the aseismic design method of nonstructural elements was also developed. Research was mainly focused on the estimation of story drift as well as the detailing of joints of metal and precast concrete curtain walls to the primary structure to accomodate the story drift. In the case of special buildings, such as super high-rises, the technique of using curtain walls which can accomodate the story drift was essentialy established. However, there are still many ordinary buildings, in which no special attention is paid to aseismic design of nonstructural elements.

Regulations and Recommendations

In so-called new aseismic design method in Japan, an epoch-making provision was introduced which restricts story drift of primary structures. According to the provision, the story drift should be equal to or less than 1/200 radian (1/120 radian, if there is no problem in nonstructural elements). As for the seismic behavior of nonstructural elements, the ordinance No. 109 (1971) gives some detailed provisions. Curtain walls should not fall down in story drift of 1/150 radian. The joints of precast concrete curtain walls should allow movement to accomodate story drift. In addition, geazing material should be elastic.

The guide line for aseismic design of nonstructural elements recommended by the Architectural Institute of Japan (AIJ) gives a philosophy of design as well as one of damage criteria (Ref. 1). The Building Center of Japan (BCJ) published the manuals on aseismic design of metal and precast concrete curtain walls, ALC panel exterior walls, openings (glass windows) and lath-mortar finishes (Ref. 2). The authors contributed to establish these guide lines and the design manuals by offering ideas and data.

When the diagnosis method of evaluating seismic safety of existing reinforced concrete structure was developed by the Japan Building Disaster Prevention Association (Ref. 3), the diagnosis method of evaluating seismic safety of nonstructural elements was also developed. In our proposals of the diagnosis methods, we proposed the fundamental idea of the human factor. From the view point of the safety of human life, there is no hazard if there is no people under the wall. If there is something like a balcony, the debris of the broken wall might remain on the balcony and not be hazardous to people underneath it. Therefore we proposed the human factor which consists of the following combination of two factors,

i) environment factor; the possibility of people present
ii) control factor; the existence of balconies and eaves

Experiment 1 Various Kinds of Nonstructural Walls

The behavior of various kinds of nonstructural walls due to reversal racking forces were tested (Ref. 4) The specimens and results are shown in Fig.1. Because of the limited specimens and loading cycles, the results show that allowable story drift is relatively large. But the allowable story drift should be regarded as smaller than these data for the practical design.

Experiment 2 Lath Mortar Finish on Wooden Frame

Three kinds of lath mortar finishes were tested by racking forces (Ref.5). The lathes used were expanded metal lath, wire lath and lath-sheet. The results of the tests are shown in Fig. 2. Among the three lathes, the performance of mortar with expanded metal lath was the most poor. Unfortunately, this kind of lath is widely used for exterior finishes of wooden dwelling houses in Japan.

Experiment 3 Tiled Walls of Half Scale Model

When Japan Housing Corporation did experiments on the primary structure of five storied building using a half scale model, several kinds of tiles were applied to the shear walls (Ref. 6). The most typical damage pattern was that the tiles were pulled off along the cracks on the wall as shown in Fig. 3. But if the cohesive strength between the tiles and the wall was poor, a large area of tile was pulled off.

Experiment 4 Nonstructural Elements on Full Scale Building Model

As a part of a U.S.-Japan Cooperative Research Program, pseudo dynamic tests were carried out on a seven storied reinforced concrete building. After finishing the tests on the primary structure, nonstructural elements were installed and tested (Ref. 7). The nonstructural elements tested are shown in Fig. 4. The results of the tests are summarized in the same figure. The noticeable findings are as follows;

i) Effect of spandrel wall
Effective height was shortened by the existence of a spandrel wall and glass breakage occurred in accordance with this effective height.

ii) Careful detailing is required in order to have perfect effect of the accomodation of story drift.

Experiment 5 Glass with Adhesive Film

Racking tests on glass with adhesive film were carried out (Ref. 8) The set up of the specimen is shown in Fig. 5. The adhesive film was applied with the intention to prevent the broken glass from falling off the sash. The film was effective in cases in which the film was thick enough to keep the broken glass in its original position. The required thickness is about 50μ. Temporary application of this kind of adhesive films might be effective for buildings already in existence.

Field Survey 1 Falling Distance of Broken Glass

Falling broken glass is very dangerous to pedestrians on the street. The distance of the debris of broken glass from the building surface was measured in the 1978 Off-Miyagi prefecture earthquake (Ref. 9). The results are shown in Fig. 6. The maximum distance is roughly estimated as a half of the height of the original position of the glass. Therefore to avoid the life threatening hazards of falling glass, a large enough area of balconies or thickets should be provided.

Field Survey 2 Year of Construction of Buildings with Glass Breakage

As mentioned previously, fixed glasses with hardening putty suffered severe damage. Fig. 7 shows the number of buildings, the glass of which broke during the first Off-Miyagi prefecture earthquake, versus the year of construction of the buildings (Ref. 9). Most buildings were constructed during 1960-70, when glass fixed with hardening putty was a prevalent detail. A great number of the buildings mentioned above still remain in the metropolitan area, and we urgently request that such glass and sashes be replaced by the new glazing method.

Theoretical Analysis

Concerning a wall board or lath mortar finish, the influence of the size of elements on accommodation of story drift was investigated (Ref. 10). And it is found that the greater the size of the wall board, the more difficult it is to accommodate the story drift.

CONCLUSIONS

The following proposals are based on the data presented in this paper:

1) Thickets and balconies are desirable to avoid a public hazard.
2) The seismic performance of mortar with expanded metal lath is very poor.
3) If the cohesive strength between the tiles and the wall is poor, it is very hazardous to human safety in earthquakes.
4) The effective height in connection with story drift of the building should be considered.
5) A margin to accommodate story drift should be kept open without fail.
6) Adhesive films are effective temporarily to prevent broken glass from falling.
7) The greater the size of the wall board, the more difficult it is to accommodate the story drift.

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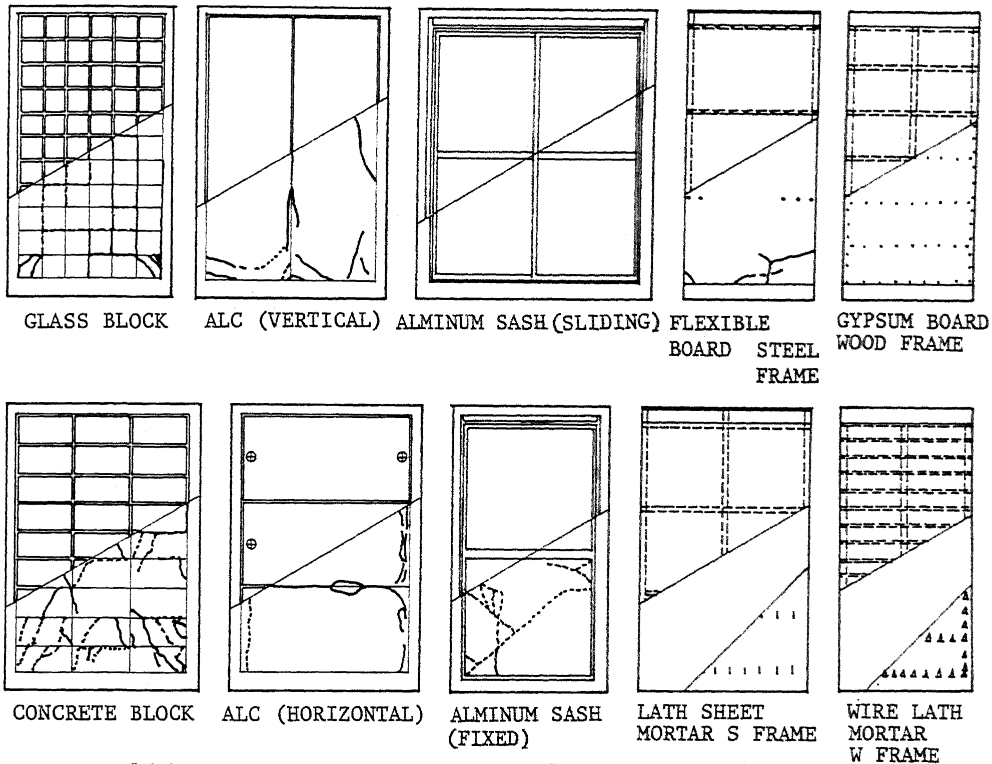


FIG.1(a) SPECIMENS OF VARIOUS KINDS OF NON STRUCTURAL WALLS

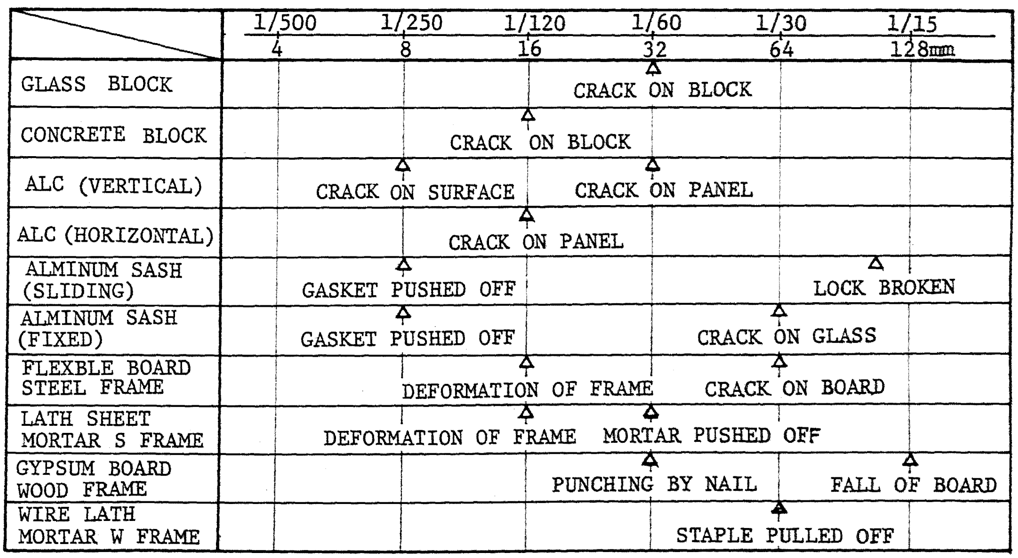


FIG.1(b) RESULTS OF RACKING TESTS

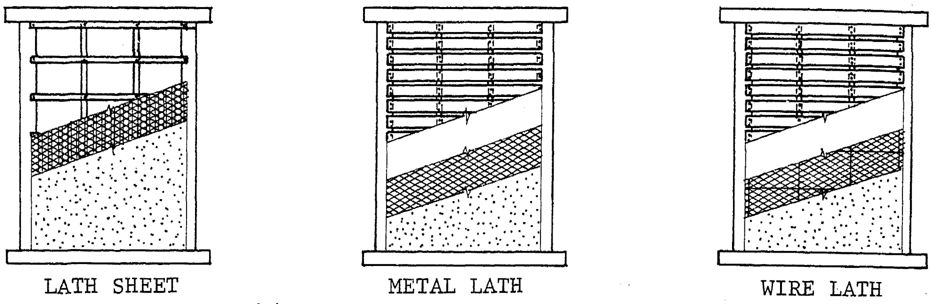


FIG. 2(a) SPECIMENS OF LATH MORTAR WALLS

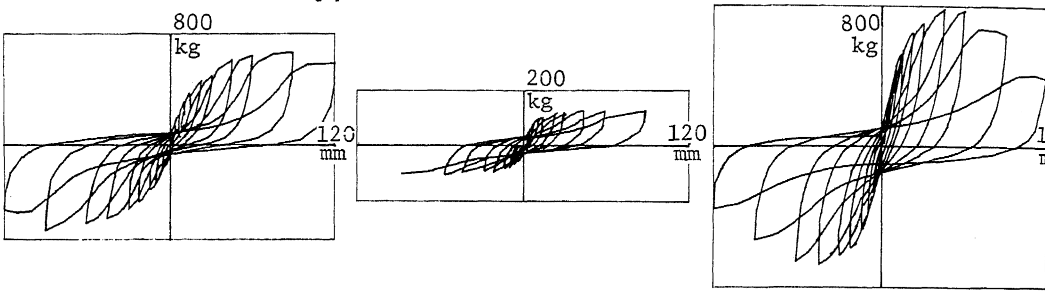
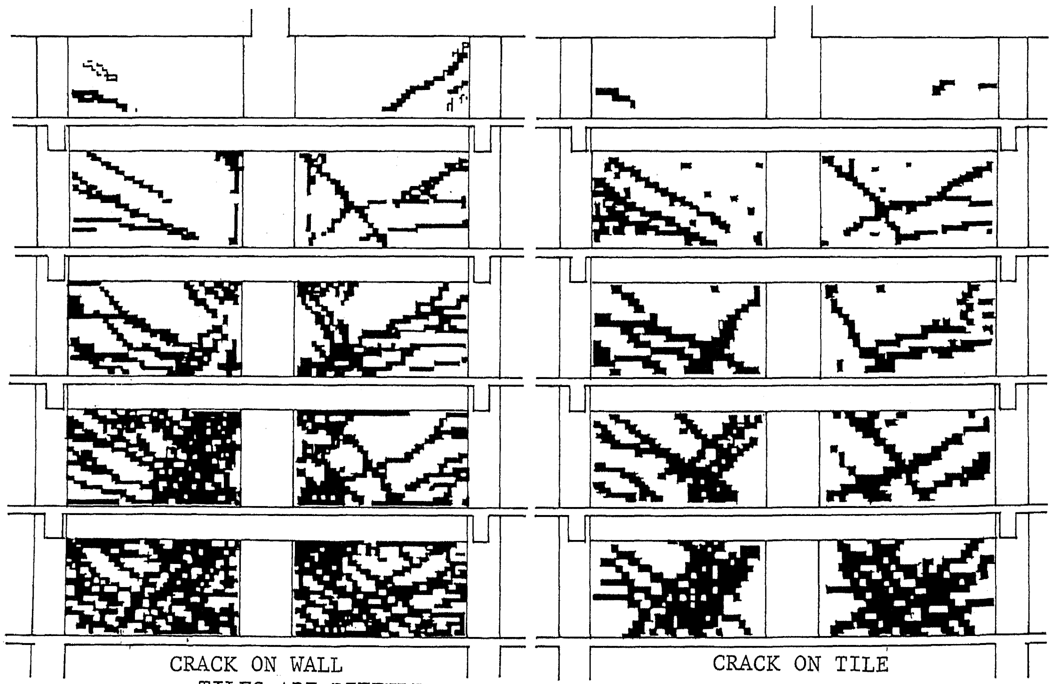


FIG. 2(b) RESULTS OF RACKING TESTS



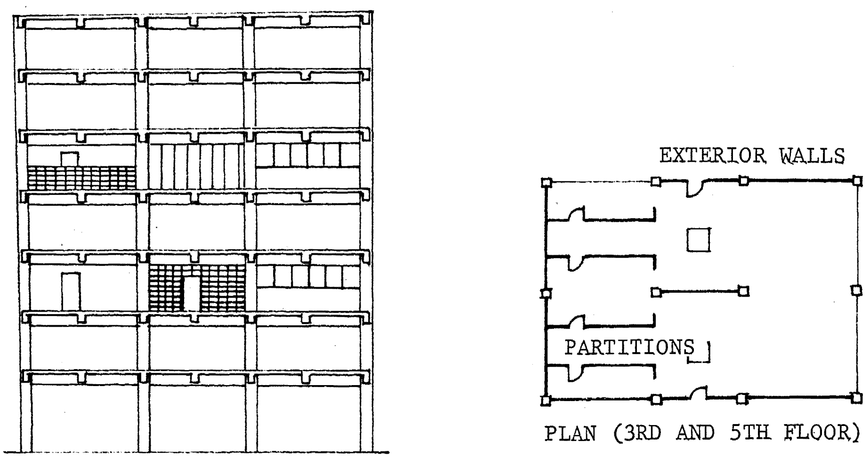
TILES ARE DIFFERENT IN SIZE AND APPLICATION METHOD

FIG. 3 SPECIMENS AND TEST RESULTS OF TILED WALLS

SPECIMEN \ DISPLACEMENT AT TOP	rad. 1/1000, 1/500, 1/250, 1/125, 1/60 — mm 22, 44, 87, 174, 348	DOOR +	DOOR −
GYPSUM BOARD/STEEL FRAME UP TO CEILING WITH CLEARANCE	SLIGHT SEPARATION OF BOARD	○ ○ ○ ○ ○ △	○ ○ △ ○ × × △
GYSUM BOARD/STEEL FRAME UP TO CEILING NO CLEARANCE	SLIGHT SEPARATION OF BOARD	○ ○ ○ × × ×	○ ○ △ △ △ △ △ △
GYPSUM BOARD/STEEL FRAME UP TO SLAB WITH CLEARANCE	SLIGHT BREAKAGE OF BOARD	○ △ △ △ × ×	○ ○ △ △ △ △ △ △
GYPSUM BOARD/STEEL FRAME UP TO SLAB NO CLEARANCE	SLIGHT BREAKAGE OF BOARD	△ △ △ △ △ △	○ △ △ △ △ △ △ △
PLASTER+GYPSUM BOARD/ WOOD FRAME WITH CLEARANCE	CRACK ALONG DOOR; MANY CRACKS FALLING FRAGMENT	△ △ △ △ △ △	○ △ △ △ △ △ △ △
PLASTER+GYPSUM BOARD/ WOOD FRAME NO CLEARANCE	CRACK ALONG DOOR; MANY CRACKS FALLING FRAGMENT	△ △ △ △ △ △	△ △ △ △ △ △ △ △
MORTAR+METAL LATH STEEL FRAME WITH CLEARANCE	CRACK ALONG DOOR; MANY CRACKS FALLING FRAGMENT	△ △ △ △ △ △	× △ △ △ △ △ △ △
MORTAR+METAL LATH STEEL FRAME NO CLEARANCE	CRACK ALONG DOOR; MANY CRACKS FALLING FRAGHMENT	○ ○ × △ △ △	○ △ △ △ △ △ × △
ALUMINUM SASH FLOAT GLASS WITH TAPE	CRACK ON GLASS/FALL (elastic seal)		
ALUMINUM SASH FLOAT GLASS WITH FILM	CRACK ON GLASS (hard putty); CRACK ON GLASS/NO FALL (elastic seal)		
ALUMINUM SASH WIRED GLASS	CRACK ON GLASS (hard putty); CRACK ON GLASS/NO FALL (elastic seal)		

○ OPEN △ TROUBLE × NOT OPEN

FIG. 4(b) RESULTS OF TESTS (PART)



ELEVATION

Fig. 4(a) INSTALLED SPECIMENS OF NONSTRUCTURAL WALLS (PART)

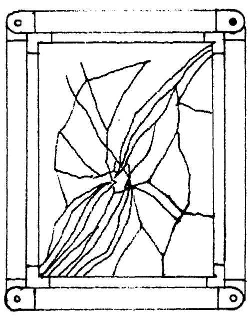


FIG. 5 SET UP OF A GLASS WITH FILM

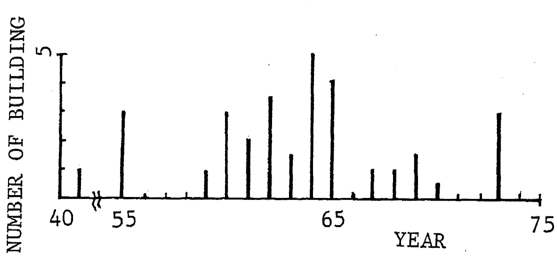


FIG. 7 YEAR OF CONSTRUCTION OF BUILDINGS (BROKEN GLASS)

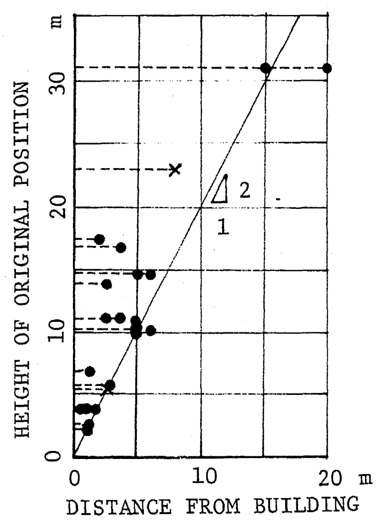


Fig. 6 OBSERVED DISTANCE OF FALLING GLASS