EXPERIMENTS ON NON-STRUCTURAL PARTITION WALLS EXPOSED TO SEISMIC FORCES

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SUMMARY

Three different design concepts for non-structural elements in earthquake resistant structural systems are presented. The need of damage control and story drift in connection with non-structural elements is emphasized, because of a strong influence of these elements in the total earthquake damage.Some comments on the newest recommendations for the design of non-structural elements are given, as well as the basis for the experimental part of the research.

A detailed behavior of two prototypes of a reinforced concrete facade panels size 704 x 245 cm is presented, as a part of a broader experimental program. The specimens were loaded by quasi-dynamic loads perpendicular to their plane. Load deflection diagrams and damping coefficient - deflection diagrams are presented. It was concluded that the panels have a satisfactory behavior under most extreme earthquake conditions.

INTRODUCTION

Bearing systems represent only a minor part of a total value in modern high-rise buildings. Non-structural components, mechanical and electrical equipment including valuable contents of users represent the larger value. Earthquakes in the last decade, especially the earthquakes in Northern Italy in 1976 and in Montenegro, Yugoslavia in 1979, according to the authors' knowledge, have indicated, that in the structures having certain bearing system which are capable to resist earthquake with unimportant or minor structural damage, because of large and uncontrolled story drift, nonbearing partition walls have been totally destroyed. Not only that human lives were endangered, but the buildings were out of service for a longer period of time.

The aim of this paper is to give a short review of the existing systems used for partition walls in high-rise residential reinforced concrete buildings. Then, the results of the experiments on selected prototypes loaded perpendicularly to their plane are presented. The experiments were carried out by cyclic loading in a servo-controlled equipment using quasidynamic loading history.

CONSTRUCTION CONCEPTS OF NON-STRUCTURAL ELEMENTS IN A SEISMIC RESISTANT STRUCTURAL SYSTEM

Three different construction concepts for a non-structural elements are known.

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According to the first concept the non-structural elements are constructed so that a full contact with a basic, bearing, earthquake resistant structure is achieved. This contact can be such that the "structural" connection exists or does not exist and that the only connection is achieved by friction or adhesion. The pure structural connection is achieved by reinforcement or by other means. It is not known in advance if during the earthquake the damage of non-structural elements will occur.

Usually the seismic design is made without taking into account the non-structural elements. Thus the more flexible system in the design is obtained. Normally, the story drifts are not calculated, and nobody assumes that the non-structural elements will take a part of the earthquake loads in their own planes. Since the non-structural elements have to follow the main bearing structure, they will via facti participate in bearing the seismic loads - regardless of how the design was done. Therefore, the actual bearing system has the larger initial stiffness. The initial seismic loads are therefore increased, and the distribution of those to the individual parts of the structural system can be substantially different from the distribution assumed in the design. The actual distribution of seismic forces, and consequently the damage distribution is dependent on the relation between the stiffnesses and the strenghts of a individual parts in the structural system.

Neglecting the infill participation, the building behavior is unknown. Therefore, from the design viewpoint, neglecting the non-structural elements, which are in contact with a structural system, the design can be judged as deficient. Numerous examples of flexible frame structures having thin clay brick infill walls (7 to 12 cm thick) aknowledge these facts.

In a second concept, the non-structural elements are constructed so that they are in contact with a structural system, but this fact is taken into account in the design procedure. Here, the design and the actual structure coincides. To make a correct design, it is necessary not to check the stresses only, but to give some possible vidence for a horizontal system dift. It would be of interest to know the story drift at the design seismic loads, and if there is such a story drift that some non-structural damage could be expected.

Existing codes restrict the story drift of the structural system and this is connected with their deflection capacity and with the possible secondary effects (P-delta). The deflection capacity of the non-structural systems did not draw attention in the research circles, and the calculated values can not be taken as reliable. It is necessary therefore, to find out what is the allowable story drift for different non-structural elements types. It would be convenient to define two criteria:a) the deflections at which the first small cracks appear and b) the deflections at which bigger cracks can occur but the human lives are not endangered. The experiment should be performed in a way which simulates the earthquake conditions (quasi-dynamic test).

In the third concept the non-structural elements are separated from the structural system and they are not taken into account in a seismic computation expect when the masses are calculated. Here, the physical separation of structural and non-structural elements is fully achived. In this case the non-structural elements either stand or are suspended on the structural elements. This is a theoretically sound concept, but a lot of architectural problems arise. Since by using non-structural elements the larger space is divided into smaller units, a prescribed acoustic and thermal insulation should exist between these units, and in the case of facade elements the water impermeability should also be achieved. The non-structural element can not fullfill all these functions if it is not in contact with a structural system. Probably this concept can be useful only in a limited number of cases where the acoustic and thermal requirements are not of the utmost importance.

Loads the sense of which is perpendicular to the plane of non-structural elements can sometimes in the stronger earthquake cause badly damages or even failures. The best way to transfer these loads is to fix the non-structural element to the main structure along all four edges. Constructed as cantilever elements they can not withstand the horizontal forces. If fixed along all four edges, they will probably be safe in the perpendicular sense, but such a fastening is opposite to the first and the third concept described above.

PROVISIONS AND RECOMMENDATIONS

According to the reference (3), section 3.8, all building parts should be designed and constructed in a way to act as a unit, with an exception if they are separated by a distance which can avoid the damage.

The distance should be at least δ_x, where $\delta_x = C_d \cdot \delta_{xe}$. In the formula δ_{xe} is the deflection calculated by elastic analysis at the design seismic loads and C_d is the deflection amplification factor which has the value of 1.25 to 6.0. The value of C_d is dependent of the type of the structural system.

The above calculated deflection should be smaller than the allowable story drift. The allowable story drift is a function of a seismic hazard exposure group. The very important structures have the allowable story dift value of h/100 and the other buildings h/67.

The seismic loads which can act on non-structural elements and their attachment to the structural system (ref. (3), sec. 8.2), can vary in a wide range of 2 to 180 percent of the element weight. The forces are dependent on three factors i.e.: expected acceleration (A=0.05 to 0.40), type and shape of non-structural element (C_c=0.9 to 3.0) and on the performance characteristic level (P=0.5 to 1.5). The earthquake load is calculated then accordin to the formula $F = A_v . C_c . P . W_c$, where W_c is the weight of the non-structural element. This load can act in the plane and perpendicularly to the element plane.

The goal of these calculations is not to avoid entirely the damage of the non-structural elements. The calculation will ensure a partial damage control which is estimated to be reasonable and possibly economic too. Since the research in this field is in the initial stage, it is not possible to correlate the increased construction costs due to the story drift limitations and repair costs of the non-structural elements in the future. One can conclude that the story drift limitations contribute to the lesser damages of non-structural elements and to the human lives protection, as a basic principle in the earthquake design philosophy.

As observed in many strong earthquakes in the last decade, large story drifts cause heavy damages of non-structural elements. The value of this damage, according to the evidence, can be larger than 50 percent of the total building value. Therefore, it is not necessary to further prove the need for a sound design of structural and non-structural elements.

BASIC CONSIDERATIONS FOR EXPERIMENTS

In a design practice up to this date insufficient attention was paid to the architectural details which could ensure earthquake resistance of non-structural elements. On the other hand, computation methods which could take into account in a simplified way the influence of the partitions and infill walls to the earthquake resistance of the building have not been widely developed.

The planned experiments are aimed to show:
1. the deflection capabilities of different types of non-structural elements in their own plane and perpendicular to it,
2. the magnitude of loads which can be transferred by these elements without any damage,
3. what are the story drifts when the cracks start, and what is the limit of the acceptable damage,
4. what are the energy absorption capacities of these elements,
5. what is the behavior at the alternate loading.

The criteria for the maximum acceptable story drift are to be expected out of the experiments for different types of non-structural elements. With these criteria, the adequate types of infill and partition walls could be selected for different structural systems (frames, frames with structural walls etc.). If data on story drift of a certain structural configuration using non - structural elements of known, experimentally determined, deformation characteristics would be known, one could find out whether the selected infill and partition walls are able to withstand such a drift, ot one could expect damage.

The experimental results on non-structural elements loaded perpendicular to their plane can be used directly in a design procedure.

It is impossible here to encompass all experimental results under the topic "non-structural elements". Subsequently, the experimental results of two large facade panels are presented.

EXPERIMENTS ON NON-STRUCTURAL ELEMENTS LOADED PERPENDICULAR TO THEIR PLANE

Two reinforced concrete panels, size 704 x 245 x 40 cm, represented in Fig. 1 were tested. The panels are the prototypes of large facade elements used in industrialized construction. The main "bearing" part of this non-structural element is the TT girder having 30 cm height, 5 cm slab and 12 cm web thickness. The main reinforcement is 2 Ø 19 mm deformed bar. Five centimeters thick thermal insulation of styrofoam is placed on the TT girder slab. The interior cover consists of a 5 cm thick reinforced concrete slab. Both RC slabs are connected with a spider-shaped piece of inoxidable steel. The panel B has the window opening size 100 x 180 cm.

In the test the load perpendicular to the panel plane was achieved by two line concentrated loads placed in quarter span in the testing frame, as represented in Fig. 2. Quasi-dynamic test was performed using a double-acting hydraulic jacks and servo-controlled deflection.

The load history is represented in Fig. 3, and the deflection lines along the span in Fig.4. Deflection capacities of panels are represented in Fig.5, where the limits of 1G and 2G (G= the weight of the panel) as absolutely upper limits of possible loads are given. It is shown that the panels have a high failure safety, and that the load deflection line is very linear in the range of possible loads.

No difference was observed between the behavior of panel without and with opening.

The failure load is much higher then calculated. The experiment has shown that the cover slab acts together with the "bearing" TT girder and that the steel "spider" has a structural function in connecting both slabs in one unit. Even in the case of a maximum load, no shear displacement could be observed. The failure occurred in huge deflections f/L=1/85 and was caused by plastic buckling of main web reinforcement in a "lower" part of a hysteresis loop, when the web was in compression. The failure was preceeded by falling off of the cover concrete and by shear cracks along the interior edge at the web - slab interconnection.

The damping coefficients have been calculated for each cycle and they are represented in Fig.6. The larger values of damping coefficients at lesser deflections can be explained by friction in the testing frame. The larger values at largest deflections are resulted by concrete cracking and well - expressed plastic behavior.

Since the behavior at the quasidynamic load as an earthquake load simulation was good, a certificate for use in all seismic zones was issued.

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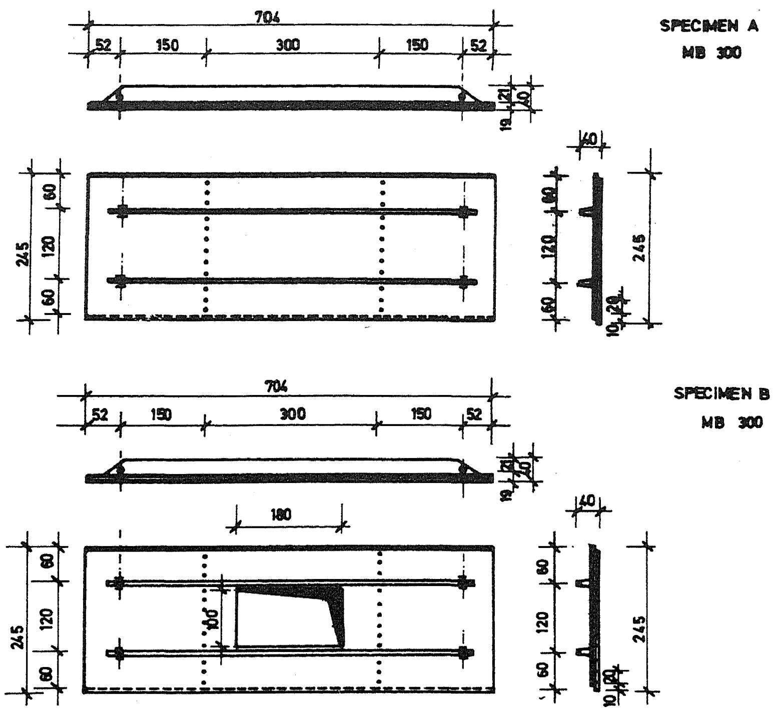

Fig.1 The shape of the tested panels

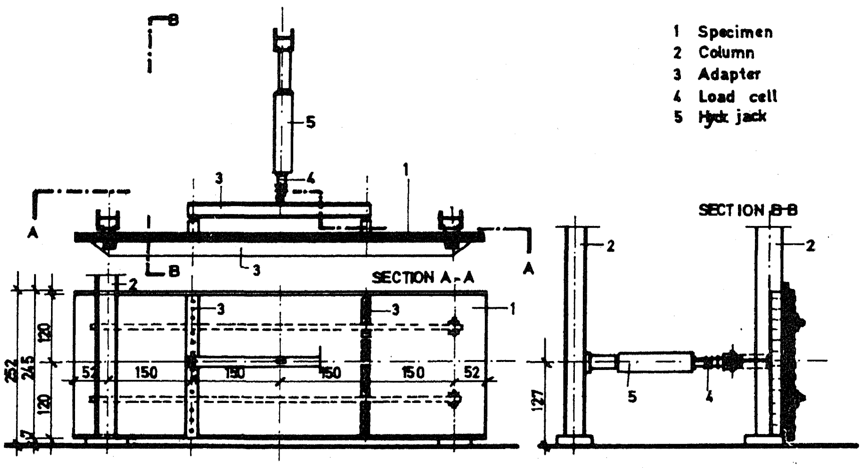

Fig.2 The position of the panel in a testing frame

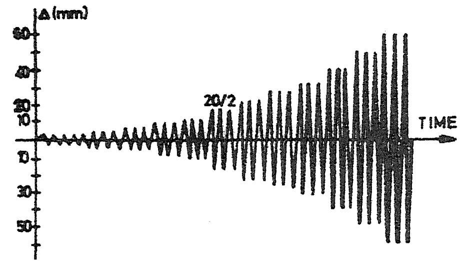

Fig.3 Load history

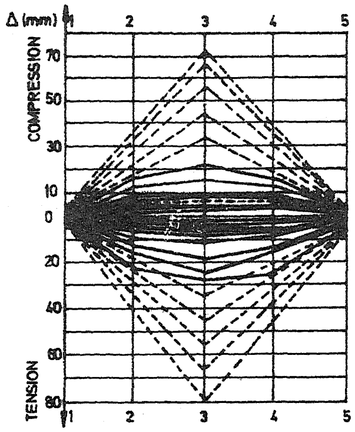

Fig.4 Deflection lines along the spar

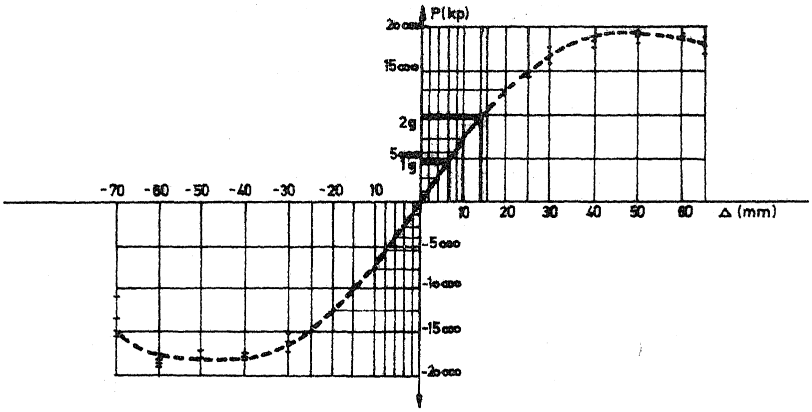

Fig.5 Line connecting the peaks of the hysteresis loops

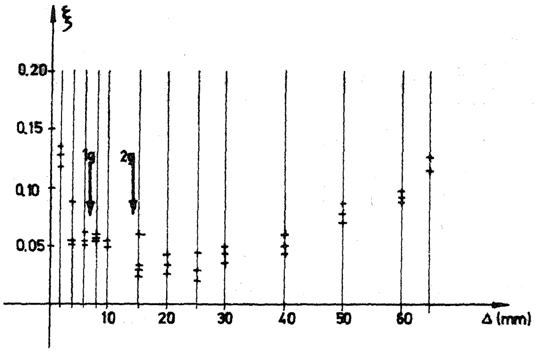

Fig.6 Damping coefficients as a deflection function