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ASSESSMENT OF EVACUATION POSSIBILITIES OF APARTMENTS IN MULTISTORIED BUILDINGS DURING EARTHQUAKES OR SUBSEQUENT FIRES, IN VIEW OF EARTHQUAKE PREPAREDNESS

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ABSTRACT

The paper presents the study of the evacuation possibilities of apartments using the analysis of the ideal and possible displacement vectors of occupants towards the exit and the possible evacuation duration for multistoried buildings, with a view to optimize the architectural lay-out and to suggest a human behaviour adequately correlated to the characteristic phases of an earthquake or of a fire following earthquakes.

STATE OF THE ART OF RESEARCH AND THE NECESSITY OF STUDIES CONCERNING THE EVACUATION POSSIBILITIES

Earthquakes and fires induce generally the reaction of evacuating the inhabited room, differing from other phenomena which are inducing a need of sheltering. Practically, the occupants evacuation of buildings having 1-2 stories, erected observing the experience and lessons of past earthquakes, becomes possible before the main phase of a strong seismic motion (Ref.1). In the same time, there are situations when buildings lack this minimal treshold of earthquake protection (Ref.2). The evacuation of multistoried urban buildings raises aspects diferring from the case of traditional houses.

The existing research and regulations are concerned mainly with the evacuation during fires or civil defense alarms. There are requirements concerning the number and width of staircases to be designed to enable all the occupants of a floor or two to enter the staircase within an acceptable period, if a fire occurs. The staircase is implicitly considered a protected area (Ref.3).

In this aim, durations of evacuation have been theoretically and experimentally analysed in Japan, U.S.A., England etc. However, in seismic zones, even when the structure did nod collapse,the staircases proved constantly to be a hazardous space. Under the effect of earthquake induced oscillations a lot of injuries and fatalities have been recorded just during evacuation on stairways. (Ref.4,5,6,8,9).

The study of evacuation possibilities of multistoried buildings is therefore considered necessary due to the following reasons:

a) because the number of typified buildings is increasing in seismic zones; for instance in Romania over 90% of the buildings erected during the last 40 years are designed using standard projects and on the other hand 60% of these are large panel, precast buildings with 5 stories;

b) in order to have a uniform method of estimating the evacuation possibilities for buildings, including the calculated time of evacuation close to the occupants possibilities, and to have a background for new design requirements providing an increased inhabitants safety. For instance, the requirement (Ref.3,4)to design the building so as to be able to evacuate the occupants of 1-2 floors in a safer place (usually the staircase) within 2,5 minutes will be neither significant nor useful in most cases for earthquakes the time is much greater than the duration of a seismic motion. In the same time this requirement could be useful in the case of fires following earthquakes within some limits.

c) in order to suggest on optional occupant behaviour during earthquake, taking into account the apartment size and type the structural system, as well as the story where the inhabitant lives as well as the characteristics of the seismic motion in the analysed zone. Some other secondary effects are to be taken into account e.g. damage, earthquake induced fires etc.

FACTORS AFFECTING EVACUATION POSSIBILITIES

The evacuation ability, under a seismic sequence action on a building, could be defined as the aptitude to leave an inhabited room, within a sufficient time,provided the occupant limb and life is not threatened. This aptitude is depending on the structural performance and the architectural layout, as well as on the aptitude of the occupant,all of them interacting with the seismic motion. The mentioned evacuation time may be influenced by several factors as follows:

. the seismic motion - could be divided into the following phases (Ref.11,13) :

- the initial phase with oscillations of o.ool-o.o2(o.o5) g and a duration of 2-18 s;
- the main phase with oscillations exceeding o.o5 g, mostly o,1-o,2 g, and a duration of 1o-5o s (for magnitudes 5.5-8);
- the final phase of damping below the perception limit and a duration of 17-30s;

. the time between the beginning of damage and the collapse is difficult to be evaluated (Ref.12). In this study this item will not be considered relevant in conjunction with the subjective and objective occupant reactions.

. the apartments lay-outs, area and distance to the staircase are different. Nowadays, in Romanía the 2 room apartments have 52-61 m^2, 3 room apartments have 66-77 m^2, 4 room apartments 81-93 m^2 and 5 room apartments 98-110 m^2 useful area. Layouts are under continous evolution : row of rooms, L or T shape, interconnected rooms a.s.o. staircases are also placed in different manners;

. the rooms furniture although various, is relatively typified by the manufactures according to the room destination and present apartment size.

Taking into account the dimensions ratio and the overturning acceleration the most prone to fall are the staggered book cases (A_H=140-210 cm/s^2), high glass cases (A_H= 210-340 cm/s^2) placed in the living room or exit corridors involving risks for occupants (Ref.5).

. the physiological and psychogical human response, specific during an earthquake may not lead to evacuation or could quick it up, function of the occupant experience of living in seismic zones, in a multistoried building, his trust in the structure strength, taking into account the age, sex, profession, earthquake education, familly structure etc.

. <u>the physiological response tresholds</u> for the 0.1-10 Hz range, according to ISO norms, indicate the vibration perception at 0.001 g-0.01 g and the annoyance sensation at 0.015 g-0.02 g, values specific to the initial seismic phase. The tolerance treshold of 0.10 g-0.25 g (0.5 g) belongs to the main phase. It is generally admitted that over 0.2 g the standing and walking without support is difficult, sometimes starting with 0.1 g. For an amplification factor of 1.5-2 one can obtain 0.2 g at upper stories when the ground motion is 0.1 g (VII MSK degree), such situation being of interest for 50% of the Romanian territory (Ref. 11).

Having in mind all these factors, one can accept the initial seismic phase as <u>the indecision phase</u> in the occupant response and the second phase as <u>the decision and beginning of evacuation</u>. This flow of response phases is true as a general trend but not so simple, and studies mentioned in Ref. 6,7,8,9 are a confirmation based on occupants behaviour survey using questionairies. The ratio of people attempting different kinds of evacuation is of 25% to 60% in Japan and U.S.A.

In Romania the questionaire survey revealed that in the same time with the increase of number of apartments in buildings having 5-11 stories decrease the number of occupants learing or trying to leave the building at earthquake (60% in 1940, 37% in 1977, 10% in 1986). This fact seems to be correlated to the experience of living in higher buildings (Ref.10) but also to the good behaviour of the new high-rise apartment buildings during recent earthquakes (Ref.11).

For persons walking under earthquake shaking, speeds of 0.3-0.5 m/s for adults are admitted and of maximum 0.3 m/s for children and aged people.(Ref.2). For stair descending the author assessed by experiments the following velocities: 0.3 m/s (2 steps/s) for teens, 0.2 m/s (1.5 steps/s) for adults and 0.1 m/s (0.75 steps/s) for children, old people etc (Ref.5). As for evacuating crowds, in other studies speeds of 1.3 m/s on corridors and 0.5 m/s on stair were assumed, but without seismic motion (Ref.3).

THE PROPOSED EVALUATION METHOD

<u>For apartments</u>, the nominal evacuation factor is defined by the ratio:

$$e = \frac{|\bar{E}_i|}{\Sigma|\bar{E}_p|} \leqslant 1 \qquad (1)$$

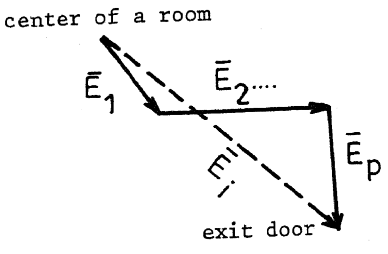

Fig.1 Displacement vectors

where $\bar{E}_i$ = the ideal displacement vector straight towards the exit door.(Fig.1).
$\bar{E}_p$ = the possible displacement vectors towards the exit door according to the architectural lay-out of the apartment

These vector originate in the weight center of the analysed room. The evacuation ability of each room is function of ratio "e" as well as of $\Sigma|\bar{E}_p|$. The influence of lighting could be introduced conventionally using a factor of 1.1 for natural lighting and 1.3 for artificial lighting applied to $\Sigma|\bar{E}_p|$ to compensate the time for light-on or the delay in case of break-out.

As a result of the analysis of several apartments in 5 and 9 storied typified buildings in Romania, the following can be stated (Ref.5).

- the values of $\Sigma|\bar{E}_p|$ increases proportionally to the number of rooms; living rooms can be evacuated more easily, being placed near the exit; for bedrooms, $\Sigma|\bar{E}_p|$ is 5.75 m at 2 room apartment, 6.6-7.1 m at 3 room apartment and 6.6-8.7 m at 4 room apartment, in 5 storied buildings and respectively 6.1 m, 6.0-8.5 m and 4.65-9.25 m for apartments with the same number of rooms in 9 storied buildings;

- the "e" ratio has values of 1.000-0.909 for 2 room apartments but may reach values between 0.862-0.637 for bathrooms and kitchens in apartments with 3-4 rooms, these presenting a reduced evacuation possibility;

For staircase the modulus of the vector defining the displacement on the floor outside the apartment and on the line of slope (flight) between two floors is expressed as follows :

$$|\bar{E}_p| = (H_{story} \cdot p + \Sigma|E_{floor}|) i \cdot n \qquad (2)$$

where:- H_{story} - height of a story

- $|\bar{E}|_{floor}$ - the possible displacement vector on the floor towards the stair.

$r = 1.0$, for direct flights
$r = 1.1$ for flights interconnected by one landing
$r = 1.2$ for flights interconnected by more landing
$i = 1.0$ for natural lighting, during the day
$i = 1.1$ for natural lighting, during the night and if electric lighting
$i = 1.3$ for electric lighting, during the night
$n = 1.0$ for 1-4 apartments per 1 staircase
$n = 1.1$ for 5-8 apartments per 1 staircase
$n = 1.2$ for more than 8 apartments per 1 staircase

For the floor lay-outs including acces corridors between the door apartment and the flight, it could be used a ratio "e" similar to the case of apartments, with the origin in the exit doar and the end at the first step on the slope line. As a result of the staircase analysis of the 5 and 9 storied buildings it has been remarked that occupants have to travel only between two floors echivalent distances of 5 to 10 m for 5 storied buildings and of 5.1 to 16 m for 9 storied buildings, in different conditions of lighting (Ref.5). In the analysis of the apartment and stairs an earthquake at 10.00 hours p.m. has been assumed.

THE EVACUATION DURATION

Using the above mentioned assumptions the evacuation duration is expressed by:

$$T_{ev} = T_1 + T_2 + T_3 \qquad (3)$$

where : T_1 = indecision interval dependending mainly on the function of room where the occupant feels the oscillation, this time being shorter than the first seismic phase. In this study T_1= 5 s for the living room, 10 s. for kitchen and bedrooms, 15 s. for the bathrooms, lavatories a.s.o. taking into account the suplementary actions to be performed by the occupant before the evacuation (to turn-off the fire-in the kitchen to and the water-in the bathroom, combined to the dressing)

T_2 = apartment evacuation interval, calculated function of the displacement towards the exit $\Sigma|\bar{E}_p|$, the walking speed under oscillations as well as using a penalizing factor equal to 1/e applied to $\Sigma|\bar{E}_p|$ in order to introduce the increasing effect of the corridors and the general layout;

T_3 = staircase evacuation interval, calculated with the consideration of walking speeds under oscillations on floors and stairs, the modulus of $\bar{E}_p$ and, if applicable, a penalization with 1/e calculated for the geometry of corridors outside the apartment.

Finally, for the buildings with 5 and 9 stories, the total evacuation time range as follows:minimum 18 s (ground floor) - 69 s (4-th floor) and maximum 88 s (ground floor) - 308 s (4-th floor) in case of 5 storied building and respectively minimum 19 s (ground floor) - 131 s (8-th floor) and maximum 57 s (ground floor) - 659 s (8-th floor) for the 9 storied buildings.

The evacuation duration on the staircase becomes dominant for upper story apartments (71% of the evacuation time for the top floor in the 5 storied building and 93% of the evacuation time for the top floor in the 9 storied building.

FINAL REMARKS

1. Using the proposed method, the evacuation possibilities of apartments as well as the contribution of staircases in the total duration of evacuation could be analysed in a simple and uniform manner. Case studies on 5 and 9 storied buildings in Romania indicate that the equivalent distance to be traveled by the occupant, if evacuation decided, will be between 5.75 m-18.75 m for 5 story buildings and between 11-137.25 m for 9 story buildings. A comparison to the data given in Ref.7 indicate for actual earthquakes distances up to 17 m, corresponding to the apartments of first and second story in our study.

2. The evacuation duration for the occupants of larger apartments (but implicitly with a more complicated lay-out), located at upper floors, is higher than the total duration of on earthquake. Therefore the strong oscillation phase will find the evacuating resident on the staircase. Assuming a supplementary effect of crowds, the evacuation time may surely be much longer than the motion duration (Ref.3).

In case of fires following certain seismic effects, the evacuation within the limits of mentioned times may coincide in some cases to the flashover time (after minimum 200 s) period accompanied by a heavy and sudden release of smoke and CO, producing the inhabitant asphyxia. In such cases, a prompt evacuation decision is necessary, except the availability and use of special devices for fire fighting (Ref.14). Therefore the lodger has to be informed and preferably trained too about all situations to occur, and to make a rough assessment of the room used as an escape route.

3. The size, lay-out and general arrangement of rooms in apartments and of apartments on the floor, of the size and type of staircase could be optimized. In this aim a collaboration of architects, engineers, earthquake engineering specialists, fire fighting officers and sociologists in order to provide shorter evacuation times for recommended situations is strongly emphasyzed.

4. For further studies there is a strong need to improve such methods of assessing the evacuability as well as to calibrate the proposal auxiliary factors. The effects of furniture placement of other sociological and physical factors have to be analysed in detail in relation to the evacuation ability.

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