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Modeling of search-and-rescue activity in an earthquake

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ABSTRACT: A computer model for the assessment of live- and dead-recoveries from a collapsed building in an earthquake was developed. The model includes, first, the deterioration of the health condition of the trapped victim and, second, the effectiveness of search-and-rescue resources. Extrication data obtained from an engineered building that collapsed in the 1985 Mexican earthquake were applied to the model to demonstrate its performance. Items for on-site investigations in a future building collapse and subsequent response activities were proposed.

1 INTRODUCTION

Very little is known about victims injured and trapped in a collapsed building. We do not know how they survive under debris or how they are brought out in the course of rescue activities.

This shortage of knowledge is due to the following two reasons:

1) We still do not have enough data presenting comprehensive and complete descriptions of events; including the situation of entrapment, injury severity of trapped people, and the effectiveness and sequence of rescue activities.

2) We still do not have any models or theoretical frameworks to describe the events that follow the collapse of buildings. In addition, we have not yet identified any factors that affect the sequence of rescue efforts.

Collection of data, particularly in the field of disaster studies, always requires a long period of time. Currently, good documentation of human casualties due to earthquakes is available only in a very limited number of publications. It will, therefore, be necessary to expend considerable effort in facilitating the accumulation of data in the future.

In contrast, the development of computer models for rescue activities and their sequences does not require as much time. It may be possible to identify significant factors affecting the results of rescue activities with only a limited range of direct experience.

This kind of development is important and useful in directing the method for data collection in future events. Even the most extensive reports of past earthquakes are based on less than comprehensive data collection.

In this study, we first identified factors affecting the recovery of trapped victims from a collapsed building, second, integrated the above factors into a computer model and, third, applied the model to the case of the Juarez Hospital collapse in the 1985 Mexico City earthquake to demonstrate its effectiveness in simulating events.

2 FACTORS

We focused on two aspects of the event as follows:

1) Survival of trapped people in a collapsed building. This is the problem of survival without food, water, relief, or medical attention. We must evaluate survival rate as a function of time.

2) Extrication of victims from a collapsed building. This is the problem of extrication effectiveness, which is affected by the condition of entrapment ,i.e., the difficulty of the extrication, and the application of rescue resources over time.

These two aspects are discussed separately in the following two sections.

2.1 *Survival*

2.1.1 *"Fade-away" function*

The function of time to define the deteriorating health condition of a trapped victim (fade-away function) was give as follows:

$$h(t)=(a_0^{1/N}-t/D_0)^N \quad (1)$$

where

h: Animation score

a_0: Animation score at t=0

D_0 and N: Coefficients

t: Time (hour).

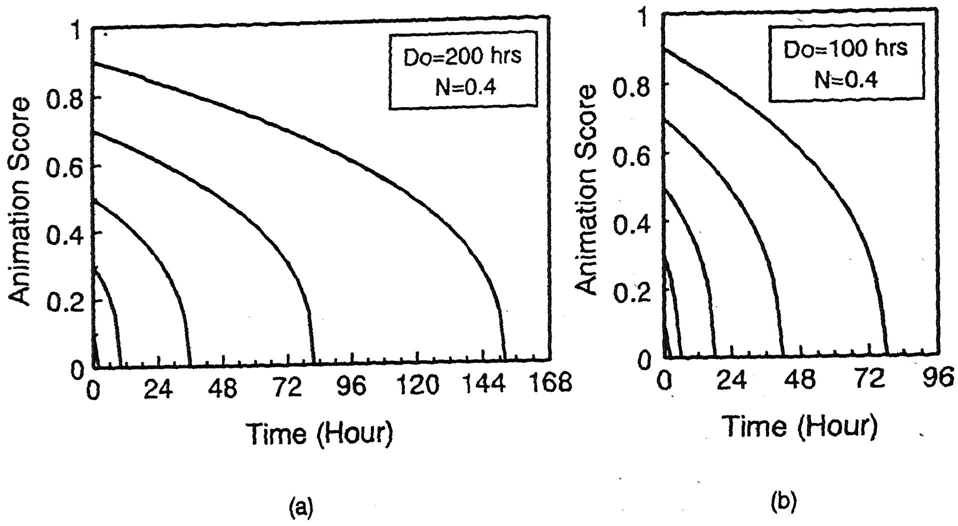

Figure 1. Examples of fade-away functions. There are two parameters that affect the general pattern of a fade-away function, Do and N. "Do" determines the duration which a trapped victim deteriorate to die; "N" determines the rate, or speed, of deterioration with time.

A victim's health condition is measured according to an index termed the "animation score," which assigns a continuous value between 1 and 0. A score of 1 represents an unaffected condition, or good health, while a score of 0 represents no animation, or death.

The animation score implies a given time period during which a survivor's health condition deteriorates toward death. In this sense, it does not necessarily correspond directly to the conventional scale for scoring injury severity. However, a reasonable relationship between the animation score and injury severity will probably be established with the accumulation of knowledge in the field of emergency medicine.

A few examples of the fade-away function are shown in Figure 1. The curves indicate how an affected victim deteriorates toward death during entrapment. For example, in Figure 1 (a), a person with an initial animation score of 0.7 can live for approximately 80 hours. The victim will die after this period of fade-away time (FT).

A victim who is affected severely by direct impact during the building collapse is given a lower animation score at the moment of entrapment (t=0), as he is closer to death and accordingly has a shorter FT. Among the curves in Figure 1, those located in the lower part correspond to the fade-away process for such severely affected people.

Even a victim with a very slight injury, which itself is not fatal, can die of dehydration or minor bleeding after a considerably long FT. The curves appearing in the upper part of Figure 1 are indicative of these victims who are only slightly affected at the first moment of entrapment.

The general pattern of a fade-away function is determined by two parameters, Do and N, which represent the environmental factors and the victim's pre-collapse health conditions, respectively.

Environmental factors, Do, affect the length of FT. Conceptually, this is the FT for a person trapped with no injuries who may die of dehydration or exposure. We must also determine Do with due consideration to other environmental factors such as the weight of debris under which a victim is pinned. Furthermore, it is necessary to include the pattern and extent of building collapse, in addition to weather and other environmental conditions. Among the factors related to structural damage, the amount and quality of interior space remaining after collapse is significant.

Pre-collapse health conditions, N, are used to define the rate, or speed, of deterioration of a victim's health condition. However, we cannot, at this point, further discuss the determination of N, since we do not yet have an explicit definition of health status corresponding to any value of the animation score between 0 and 1.

2.1.2 Survival rate

Once it is possible to follow the change in an individual victim's health condition over time, we should be able to derive the survival rate for all trapped victims in a collapsed building as a function of time. This transition requires the distribution of injuries, i.e., the number of victims in each category classified by animation score.

2.2 *Rescue*

2.2.1 Extrication difficulty

To understand an entire disaster from the rescue point of view, information about both the total number of trapped people and the difficulty of each extrication is required. Extrication difficulty for a particular victim depends primarily on the physical conditions of the entrapment which relate to the structural type of the building and the pattern and extent of collapse.

We initially evaluate extrication difficulty along a three-tiered scale of "easy, moderate and difficult" by the amount of rescue effort needed for the extrication of a trapped victim. This process requires the use of a scale of equivalent manpower based on the man-hour unit.

The evaluation of rescue resources in terms of man-hours of rescue effort seems appropriate because it is simple and familiar. However, when it is used to simulate an actual sequence of a rescue operation, the concept of the man-hour is inadequate. Effectiveness of rescue activity, particularly in the case of heavy rescue, depends on the efficacy of training of the rescuers and the provision of sophisticated and heavy machinery. We must, therefore, develop some scheme to evaluate the effect of such variables on an "equivalent" man-hour scale.

2.2.2 Effective resources

In addition to the evaluation of professional skill and equipment, that of effective man-power is equally significant. We have to determine the number of rescuers surrounding a collapsed building who are actually involved in direct efforts, such as the removal of debris and tunneling.

Among the people engaged in rescue activities, a considerably large portion of rescuers are indirect participants, i.e., providing support and management. The proportion of rescuers performing indirect tasks becomes larger as the total number of rescuers grows. The reasoning for this is that a large assembly of rescue teams requires more ancillary support.

2.2.3 Extrication

Once we are given, first, the number of trapped people classified by the level of extrication difficulty and, second, the number of rescuers, which increases as time goes on, we can calculate the number of people extricated during sequential time segments starting at the moment of building collapse.

In the calculation, we introduced an additional assumption that the rescue effort made in a collapsed building is distributed among the victims trapped in each extrication difficulty level in the ratio of 10:3:1 (easy, moderate and difficult) at any moment during rescue activity. We used this assumption to include a sequence as follows: in the course of extrication of one person, other victims have a better chance of being located and rescued.

3 COMPUTER MODEL

We have thus developed two complementary models: one for survival and one for recovery of trapped victims. It should be possible to assemble them into a comprehensive model to represent the potential for live- and dead-recovery from a given collapsed building.

The combination of these two elemental models is reasonable as long as we can use the assumption that FT (fade-away time) and extrication difficulty for a trapped victim are independent. Although we have to examine this simple assumption more carefully in future, it is not appropriate at present to assume more complicated situations. Our data are still too limited to support more sophisticated hypotheses.

We applied the model to a series of hypothetical collapse situations. The results obtained were based on many assumptions rather than on extensive hard data, but they did illustrate the consistency of our model with actual field experiences.

4 TEST

A useful data set detailing the recovery of trapped victims is available from the collapse of the Juarez Hospital in the 1985 Mexican earthquake (Krimgold, 1988). The day-by-day live-recovery rates derived from the data reported by Rojas Enriquez (1987) are shown in Figure 2.

In applying our model to the case of the Juarez Hospital, we hoped to demonstrate that the model was capable of revealing some of the facts hidden within this complicated event which took place in the collapse of a high-occupancy, engineered building.

A remarkable aspect of Figure 2 is the invariable rate of live-recovery during the first five days after the collapse. The rate of live-recovery during this period is approximately 70 percent. This suggests that the deaths of the trapped people occurred only within a short period of time, probably in the few hours immediately after the collapse. During the latter part of the first day and the following four days, an insignificant number of deaths occurred in the building.

The rate of live-recovery decreases, slowly at first and then gradually more rapidly after day 6. It reaches zero by day 9. This suggests that the condition of the trapped victims who escaped immediate death gradually deteriorated during the first five and the following four days, and that they died in the period between days 6 and 9.

In order to simulate the survival rate discussed above, we used a fade-away function with Do=200 hours (see Figure 1 (a)) and the distribution of trapped victims by animation score at the moment of entrap-

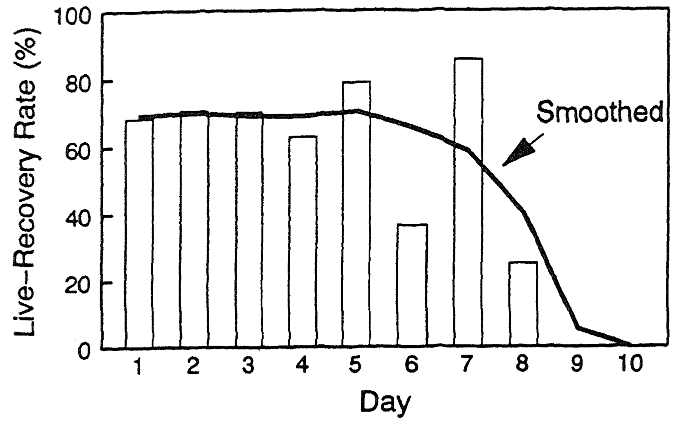

Figure 2. Live-recovery rates of the trapped victims from the Juarez Hospital collapsed in the 1985 Mexican earthquake (after Enriquez, 1987).

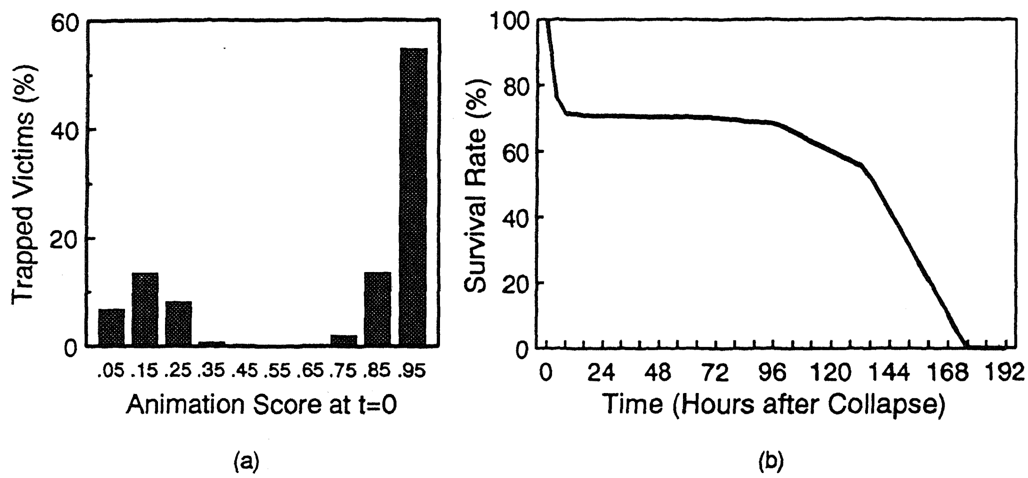

Figure 3. Survival of the trapped occupants in the Juarez Hospital, Mexico City, 1985. Initial distribution of the trapped by animation score (a) and the survival rates (b).

ment shown in Figure 3 (a). These two assumptions, which we still cannot readily conclude to be definite or optimal, led us to the resulting survival rate function shown in Figure 3 (b).

We originally classified extrication difficulty into three levels. After a trial and error sequence to obtain a good fit between the reported data and our calculations, we determined the score for the three levels of extrication difficulty to be 8, 30 and 250 man-hours. These numbers correspond to the levels of easy, moderate and difficult, respectively.

Gross and effective rescue power values, in terms of the number of rescuers, we assumed in this simulation are shown in Table 1.

Table 1. Number of rescuers, an assumption.

Time	Arrival	Cumulative	Effective
0	50	50	14
12	50	100	20
24	100	200	30
48	200	400	44
72	100	500	50

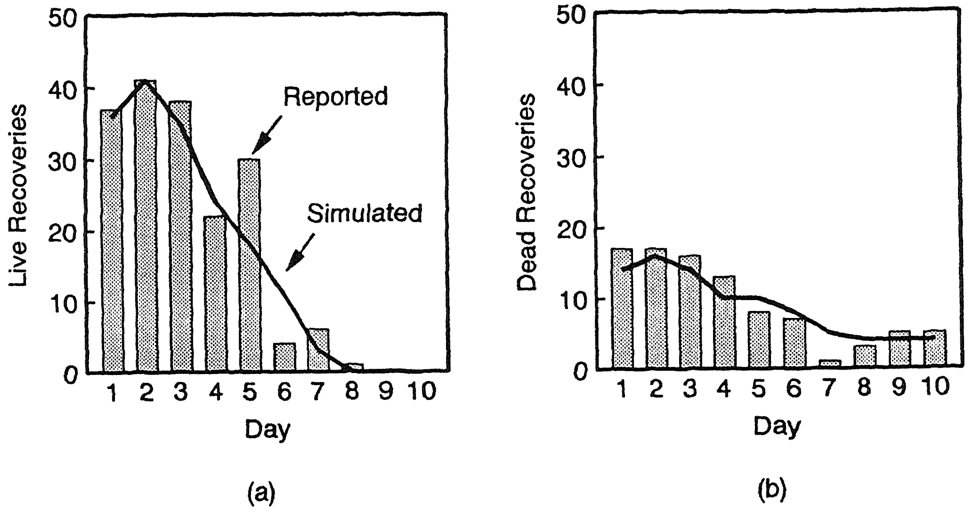

Figure 4. Live– (a) and dead–recoveries (b) from the Juarez Hospital, Mexico City, 1985.

We used the following equation to evaluate effective rescue power:

$$Re = a \cdot Rg^{n} \qquad (2)$$

where

Re: Effective Rescue Power
Rg: Gross Rescue Power
a and n: Coefficients (a=1.46, n=0.569 for a good fit between simulated and reported recoveries).

The number of trapped people at each level of extrication difficulty was assumed to be 120, 110 and 510 from easy to difficult, respectively. We determined this distribution so as to obtain a good fit between simulated and reported numbers of extracted people by day for the first ten days after the collapse. This result, therefore, was based on the assumption of the allocation of rescue power and the scores given to and the number of people in each level of extrication difficulty.

Figure 4 is the final result of live– and dead–recovery of trapped victims obtained through our series of trials and errors. We achieved a reasonably good fit between the data and calculation. Even though we require further examination of the given assumptions for various parameters, we can conclude that our model has considerable applicability to the reproduction of an observed event.

5 CONCLUDING REMARKS

A computer model to estimate the number of people extricated alive and dead from a collapsed building was developed to establish a theoretical framework to direct the method of data collection in future events. The computer model was applied to the case of a reinforced concrete building with high occupancy, the Juarez Hospital, Mexico City, to confirm its appropriateness.

This study suggested possible items to be investigated in future events, which are listed below:

1) Extrication time and health condition of each extricated victim, whether dead or alive. Health condition is to be determined in terms of FT (fade–away time) as well as the conventional measures including the affected part, type, and seriousness of injuries (injury severity score).

2) Arrival time of rescue power, including the number and quality of rescuers and equipment.

3) Type, duration, and extent of rescue activities taking place. Documentation of the number of rescuers and the items and amount of equipment.

4) Extrication difficulty as indicated by the period between the detection of a trapped victim and his extrication.

5) Construction type and damage situation of a collapsed building.

Although the following are also necessary to analyze collapse events in our computer model, it is appropriate to determine these factors indirectly through an "inversion" procedure using the computer model. These items are as follows:

1) Number, or distribution, of trapped victims in each category of health condition assigned by animation score at the first moment of entrapment (t=0), i.e., at the time of collapse.

2) Number, or distribution, of trapped victims in each category of extrication difficulty.

3) Distribution of extrication effort for trapped victims in each category of extrication difficulty.

The determination of fade–away functions (assignment of the two parameters, Do and N) is a task that may be partially achieved through the examination of existing data in the field of earthquake casualty epidemiology (for example, de Bruycker et al., 1985). We also require medical scientific information to solve this problem, even though our efforts to collect related data at future collapse sites will be indispensable.

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