ASSESSMENT OF CASUALTIES' STATES DURING DESTRUCTIVE EARTHQUAKES

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SUMMARY

During a destructive earthquake, to reduce casualties, especially in the early period after the earthquake, is most critical. Puzzles are that how the trapped in ruined buildings heads for death from initial injury state without aids, and how to describe the process, what's the best time to rescue them in this process, how to carry out self- and extra- rescue program for them before death. These surely are indispensable and helpful to emergency need, but are not yet settled worldwide.

The index of casualties $\boldsymbol{C}$ is introduced for the trapped that is still alive after a destructive earthquake to indicate his injury degree. Because the definition of $\boldsymbol{C}$ shares some common characters with that of ***SDI*** (Structure Damage Index), a possible qualitative relationship between them may exist. And, $\boldsymbol{C_0}$ is committed for the index of casualties related to the period immediately after buildings' collapse. Then, in order to describe the injury-developing process controlled by three factors: the initial injury degree ($\boldsymbol{C_0}$), the trap surroundings ($\boldsymbol{S_0}$) and the physique of the cornered ($\boldsymbol{n}$), a function ***SFC*** (State-Function of Casualties) can be naturally constructed. Through parameter analysis on $\boldsymbol{C_0}$, $\boldsymbol{S_0}$, $\boldsymbol{n}$ from six pieces of two-dimensional figures, it can be found that the trapped with weaker physique and worse initial injury degree and in more adverse trap surroundings deserves sooner rescue. Two three-dimensional figures illustrate that $\boldsymbol{S_0}$ weighs more than $\boldsymbol{C_0}$ and $\boldsymbol{n}$.

The up-to-date research all over the world related to the seismic casualties is basically qualitative, based on the post-earthquake records. This paper is expected to promote the research on earthquake-caused casualties and do some good to emergency rescue.

INTRODUCTION

During a destructive earthquake, nearly all attention is paid to the scale of seismic casualties, because, in a sense, to reduce the loss of casualties is the fundamental purpose of earthquake disaster mitigation. And to reduce casualties, especially in the early period after the occurrence of an earthquake, seems most critical; for example, to rescue by all means the trapped from ruined buildings as soon as possible. In this case, the concern about property loss is laid aside temporarily for conscience' sake. In fact, the researches nowadays on seismic casualties have worldwide become an essential aspect of earthquake disaster mitigation.

Like much damage data on all types of structures had been accumulated through previous earthquakes, recently the damage data on lifeline has also become rich. Based on the data, more and better methods of post-earthquake disaster analysis, assessment and even prediction for future earthquake event in these two fields are suggested at a high speed. However, by comparison, assessment and prediction of casualties are less advanced. The reason is that although the record of casualties in literal history is more detailed in content and more remote in time than other records of earthquakes, generally it was completed by non-governmental statistics. Furthermore, there are

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few available methods for the assessment or prediction on casualties and these methods yield results quite differently. Thanks to information modernization, the accuracy of casualties assessment or prediction is now being improved, though several factors that cause unreliable results still exist. These factors include earthquake intensity, structural damage level, the amount and density of local population, the indoor occupancy rate, the occurring time point of a certain earthquake, efficiency of rescue, self- and extra- rescue ability, the dissemination extent of earthquake-prevention in stricken area. Other casual factors bring about difficulties as well. Besides, puzzles are that how the trapped heads for death from initial injury state without outer aids, and how to describe the process, what's the best time to rescue them in this course, how to carry out self- and extra-rescue program before death. These are still unsettled from country to country, but are indispensable to the emergency need.

In this paper, based on life-vulnerability analysis, a new concept—the index of seismic casualties is proposed to describe different injury levels. Then, state-function of casualties related to trap periods is constructed when taking death-developing process into account. This function makes it possible to carry out numerical analysis on the whole process from initially injured state to deteriorating state, dying state and eventually to death.

THE INDEX OF SEISMIC CASUALTIES

The index of seismic casualties ***C*** symbolizes the injury degree of the trapped that is still alive after a destructive earthquake. Naturally, this index ranges. The injury degree and its corresponding casualties index are expressed by using ***C*** (0 for no injury and 1.0 for death). Between 0 and 1.0, five divisions indicate correspondingly five different injury degrees: intact on the whole, slightly injured, moderately injured, seriously injured, dying or dead. The injury degree and the corresponding casualties index are shown in Table 1.

Table 1: Injury Degrees (*ID*) and Casualties Index (*C*)

Injury Degree	**Intact on The Whole**	**Slightly Injured**	**Moderately Injured**	**Seriously Injured**	**Dying or Dead**
C	0 ~ 0.1	0.1 ~ 0.3	0.3 ~ 0.6	0.6 ~ 0.9	0.9 ~ 1.0

So, assessment on different injury states can be done according to the definition above. This kind of definition of ***C*** shares some common characters with the definition of ***SDI*** (Structural Damage Index). And it is believed that a possible qualitative relationship may be established between them. In other words, ***C*** will be obtained from ***SDI***.

The five injury degrees are generally described as below:

Intact on the whole: the trapped is on the whole not injured by damaged buildings; with only slight wound like rub on the skin, etc; but can act normally after being applied ointment.
Slightly injured: the trapped has no injury in head, internal organs and main skeleton; with little wound in unimportant part; but can act normally after a short period in hospital.

Moderately injured: the trapped has moderate injuries in head, internal organs and main skeleton; but with some wounds in one or more unimportant parts; needs to be in hospital for a certain period; basically will not be disabled lifelong.

Seriously injured: the trapped has some severe injuries that make him unable to control his own activity including walk; and needs to be in hospital with rescue immediately; in some case, may be disabled lifelong because of too severe injuries or not being rescued timely.

Dying: the trapped has many severe injuries and is in a state of unconsciousness; it is impossible that he could be rescued through operation.

Extra advice on describing the injury degrees can be suggested by medical experts as well.

THE INDEX OF CASUALTIES IN AN INITIALLY INJURED STATE (C_0)

C_0 is used to stand for the index of seismic casualties in the period of building collapse immediately after the occurrence of earthquake.

Obviously, C_0 depends on trap situation, construction type and damage level, or others. Specifically, if a buried man is in a trapped but free space, he will be slightly injured because of no severe wound to his fatal body part. In general, the injury caused by the collapse of multi- or supermulti- story RC structure would be more serious than that caused by low-story frame, multi-story masonry or factory buildings if these structures suffered the same damage level. In addition, the injury degree is undoubtedly heavier under collapse than under other cases such as slight, moderate or serious damage to buildings.

Table 2: Relation between C_0 and *SDI*

Structural Damage Level		Intact on the Whole	Slightly Damaged	Moderately Damaged	Seriously Damaged	Ruined
Index of Structural Damage (*SDI*)		0~0.10	0.10~0.30	0.30~0.55	0.55~0.85	0.85~1.00
Index of Casualties' State	Factory Buildings	0~0.03	0.03~0.09	0.09~0.16	0.16~0.34	0.34~0.70
	Multi-Story Masonry	**Error!**	0.04~0.12	0.12~0.22	0.22~0.43	0.43~0.80

However, two problems should be paid attention to. The first is that the difference between C_0 and the injury degree after emergency rescue ought to be discriminated, because the latter is the result of the former after an injury development course. The second is that C_0 correspondingly derived from ***SDI*** could span two injury states; for example, C_0 in case of a seriously damaged multi-story masonry is 0.22 ~ 0.43 which in fact may indicate a state of either slightly injured or moderately injured. Perhaps this reflects the impact of some random or casual factors.

STATE-FUNCTION OF CASUALTIES (*SFC*)

4.1 Concepts and Formulas:

The injury of the trapped will develop from initial state to the time point being rescued. This should be discriminated from the damage to structure. Such development is mainly controlled by three factors: the initial injury degree; the trap surroundings and the physique of the trapped. The first one has been discussed. About the second, trap surroundings, which refers to living situations for the trapped, it sometimes varies greatly. For instance, before building collapse one who received dissemination of earthquake disaster prevention will promptly enter a narrow and firm space, such as a small toilet, a limited room under firm bed or table; thus he is to enjoy a better chance for survival. S_0 is used to symbolize trap surroundings. For the third one, the physique of the trapped, it depends on age, gender and health at the point of the earthquake. n is committed to symbolize it. Based on the above, a function is naturally constructed to describe the injury development course for the trapped: ***SFC*** (State-Function of Casualties)

$$C(t) = (C_0^{1/n} + S_0\, t)^n$$

Where: t indicates time measuring that ranges from building collapse to coming of rescue. Here, $C(t)$ means that C (Casualties Index) is a function of t if under certain conditions. After study and comparison with concrete injury states of casualties in previous earthquakes, the ranges of a set of parameters may be confined as follows:

$0 \le \boldsymbol{C_0} \le 1.0$

$0.004 \le \boldsymbol{S_0} \le 0.1$

$1.0 \le \boldsymbol{n} \le 3.0$

Surely, other ranges could be applied to this set of parameters, but they have to tally with the investigation on earthquake caused damage.

4.2 Parameter Analysis:

To examine whether such parameters are able to reflect real states of casualties, analysis on them is conducted. In Figure 1, where $\boldsymbol{t}$ indicates as the above and $\boldsymbol{C}$ indicates casualties index, the effect of $\boldsymbol{n}$ (Health Attenuation Index) on $\boldsymbol{C}$ is studied. The value of $\boldsymbol{n}$ is beyond 1.0. The greater $\boldsymbol{n}$ is, the weaker a man' health will be. In this figure, $\boldsymbol{C_0}$ is given a definite value as 0.2, $\boldsymbol{S_0}$ as 0.01, $\boldsymbol{n}$ as 1.0. In 24 hours, $\boldsymbol{C}$=0.44; in 48 hours, $\boldsymbol{C}$=0.68; in 72 hours, $\boldsymbol{C}$=0.92; about in 80 hours, death befalls the trapped because $\boldsymbol{C}$>1.0. Under the same initial injury state and trap surroundings, if $\boldsymbol{n}$=3.0, which means a weaker health than that of $\boldsymbol{n}$=1.0, in 24 hours, $\boldsymbol{C}$=0.56; in 36 hours, $\boldsymbol{C}$=0.90; in 40 more hours, the trapped is dead. Like this, when $\boldsymbol{n}$ is given the value as 1.5, 2.0, 2.5, the fade-away time may be obtained as 66, 55, 48 hours respectively. Based on this, it can be got that the trapped with weaker health deserves sooner rescue.

Figure 2 studies again the effect of $\boldsymbol{n}$ on $\boldsymbol{C}$. With $\boldsymbol{S_0}$ changing from 0.01 to 0.004 which means a better trap surroundings, the same analysis is carried out when $\boldsymbol{n}$ is set a value as 1.0, 1.5, 2.0, 2.5, 3.0 respectively. The fade-away time to death when $\boldsymbol{n}$ is 1.0 can be obtained in this figure, some 200 hours. In fact, 7 days after the earthquake in Hanshin-Awaji (Japan, 1995), two persons alive were salvaged, but none saved 24 hours later. Similarly, in the earthquake in Tang-shan (China, 1976), one person was saved during the eighth day after quake, even a female worker was extricated during the tenth day. Therefore, $\boldsymbol{S_0}$ =0.004 may imitate the best trap surroundings where the trapped who is fortunately alive has a chance to maintain his life as long as possible. Through contrast between Figure 1 and Figure 2, it can be found that the trapped in different health physique conditions is sure to have different fade-away courses under the same initial injury states and trap surroundings.

Figure 3 and Figure 4 show how $\boldsymbol{C_0}$ can influence $\boldsymbol{C}$. They both have $\boldsymbol{n}$ as 2.0, but have disparity on $\boldsymbol{S_0}$. Through Figure 3, it can be inferred that if $\boldsymbol{S_0}$=0.004, $\boldsymbol{C_0}$=0.2, the fade-away time will be 138 hours, nearly 6 days; if $\boldsymbol{C_0}$ =0.4, will be almost 4 days; if $\boldsymbol{C_0}$=0.6, will be 2 days and more; but only one day if $\boldsymbol{C_0}$=0.8. Through Figure 4, in worse trap surroundings as $\boldsymbol{S_0}$=0.01, if $\boldsymbol{C_0}$=0.2, the trapped can survive 2 days and more; if $\boldsymbol{C_0}$=0.4, can survive 1 day and a half; if $\boldsymbol{C_0}$=0.6, not more than one day, if $\boldsymbol{C_0}$=0.8, no more than 10 hours. It can be seen in accordance with reality that the influence of $\boldsymbol{C_0}$ on $\boldsymbol{C}$ is obvious.

Figure 5 and Figure 6 illustrate the influence of $\boldsymbol{S_0}$ on $\boldsymbol{C}$, both with $\boldsymbol{C_0}$=0.2. But they have $\boldsymbol{n}$=1.5 and $\boldsymbol{n}$=3.0 respectively. Through Figure 5, it can be seen that the trapped having a comparatively strong physique will be greatly subjected to trap surroundings even with comparatively slight injury. When $\boldsymbol{S_0}$=0.004, he is able to survive 7 days; when $\boldsymbol{S_0}$=0.008, 0.01, 0.02, 0.04, 0.08, 0.1, the corresponding fade-away time from his initial injury to death is 80 hours, 65 hours, 32 hours, 15 hours, 9 hours, 7 hours respectively. Similarly through Figure 6, for someone with comparatively weaker physique, he can survive 105 hours (more than 4 days) if $\boldsymbol{S_0}$=0.004, but can survive only 50 hours if $\boldsymbol{S_0}$=0.008. Other fade-away time can be inferred in this figure if $\boldsymbol{S_0}$ varies. The fact that the live time of the trapped depends notably on trap surroundings is evident.

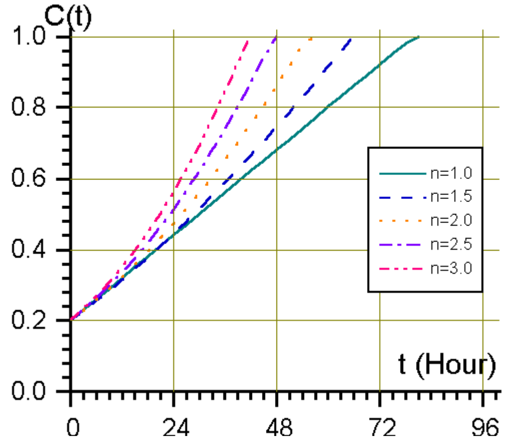

Figure 1: Effect of *n* on *C* (C_0=0.2 S_0=0.01)

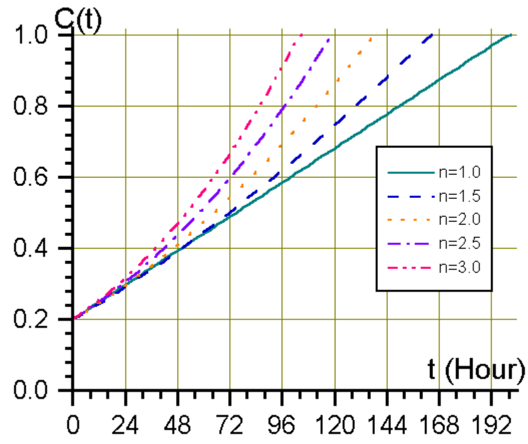

Figure 2: Effect of *n* on *C* (C_0=0.2 S_0=0.004)

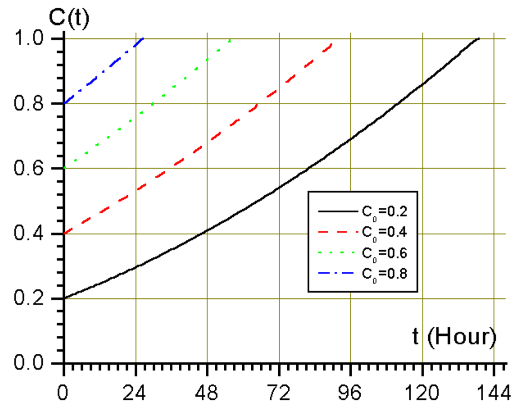

Figure 3: Effect of C_0 on *C* (C_0=0.2 S_0=0.004)

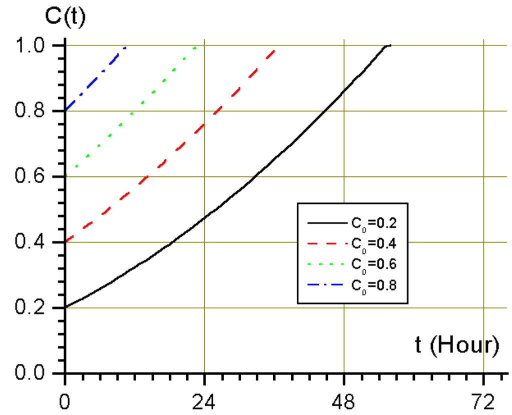

Figure 4: Effect of C_0 on *C* (C_0=0.2 S_0=0.01)

CONCLUSION

The definitions of ***C*** (Index of Casualties) and C_0 (Index of Casualties in an Initial Injury State) make it possible to assess more precisely the casualties' states during an earthquake. Through the relationship between ***C*** and ***SDI*** (Structural Damage Index), different values of ***C*** under different conditions could be got from the investigation on structural damage after earthquakes. ***SFC*** (State Function of Casualties) satisfyingly describes all the states of casualties and the results of numerical modeling on ***SFC*** vividly reflect the various stages of the injury development for seismic casualties, so that quantitative estimation may be of great help to earthquake emergency need.

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