ON THE SCALE OF HUMAN CASUALTIES DUE TO EARTHQUAKE AND TSUNAMI

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Summary

This paper examines the relation between the intensity of the external force and human casualties as well as factors affecting the scale of human casualties due to earthquake and tsunami hazards using data on hazards of the past. In the case of damages done to people who act according to their will and judgment, there is a possibility that the scale of human casualties may be significantly affected by human and social factors and accordingly may turn out fairly different depending on these factors when the external force operates with a given intensity. The number of damaged houses is a quantity which indirectly indicates the intensity of damaging impact. It is generally recognized that a high correlation exists between the number of damaged houses and the number of casualties due to natural hazards. In the case of earthquake hazards, the highest correlation is obtained when the number of damaged houses is indicated by the weighted average of the "totally-collapsed" and the "burnt-down" with the weight of unity respectively and the "partly-collapsed" with the weight of 0.2. Regression equations are derived relating the number of damaged houses and the number of casualties due to earthquake hazards in urban areas. The regression coefficient is slightly greater than unity, which implies that the number of casualties would rise at a higher rate than the increase in the intensity of damaging impact which operates on a certain urban area. The death rate for a city would be about 1 percent when it is struck by an earthquake with the intensity of degree 6 on the seismic scale, while the death rate of 0.01 percent would result from an earthquake with the intensity of degree 5. However, in the case when an earthquake is followed by a widespread fire in a large area, the death rate could reach 2 to 3 percent. The paper demonstrates quantitatively the extent to which emergency evacuation as well as variations in the damage potential and wave height would affect the number of deaths, on the basis of a comparison of damages due to tsunamis which struck the Sanriku Coastal Region in 1896 and 1933. Also, the regression equation is derived relating the ratio of tidal wave height and the damage rate.

1. Introduction

To minimize human casualties is the primary objective for any disaster prevention program. For this objective, it is useful, by investigating various cases of the past hazards, to recognize factors determining the manner in which human casualties are caused as well as factors involved in aggravation or mitigation of casualties. Moreover, it is important in establishing disaster prevention programs for a region to make predictions as to how large the scale of human casualties would be if the external force of a certain expected intensity operates over the region. In the case of earthquake hazards, while their frequency is lower than that of wind-water hazards as shown in Figure 1, there is a greater possibility that the scale of human casualties would be extraordinary. Therefore, estimation of the scale of casualties is very important for earthquake hazards. Because of the low frequency of earth- quake hazards, we have no choice but to include hazards of the long past as samples for case study. In so doing arises a serious problem of evaluating quantitatively the effects on the scale of casualties of social factors that are subject to large changes over time, if we are to link the analysis with prediction of the future.

In this paper, we examine, in the cases of earthquake and tsunami hazards, the relation between the intensity of the external force and the scale of human casualties as well as factors affecting the latter from a rather macroscopic viewpoint using the data on damages caused by the past hazards. Unlike damages done to structures or facilities that are fixed on land, those done to people who act according to their will and judgment are subject to human and social factors. Accordingly, the external forces of a given intensity may cause a widely varying scale of human casualties depending on these factors. In the case of tsunamis the area of potential danger is limited and sufficient time passes between the moment when it is generated and the moment of its arrival. Under those circumstances the scale of human casualties may be affected to a great extent by factors such as awareness of residents against hazards, transmission of information and evacuation in emergency.

2. Earthquake

2.1 The Relation between Housing Damage and Human Casualties

The earthquake is generated at a certain point in space and a certain point in time. Being transmitted through the crust with a diminishing intensity according to the distance from the focus, earthquake waves are then subjected to amplification according as the degree of firmness of the ground before they operate as an input on the system above the ground where people form a society. The intensity of earthquakes is indicated by such quantities as magnitude on the Richter scale, intensity on the seismic scale, acceleration and so on. It entails a relatively clear-cut process which begins with the emergence of the force and through the operation of the force on the ground surface ends with damages to structures. While floods or landslide plus debris-flows take place only locally in relation to the area upon which the primary external force operates (i.e., the rainfall area), the earthquake involves a kind of damaging impact that operates globally on the affected area. For these reasons, various equations have been derived relating the scale of housing damages and the factors that determine the intensity of earthquake vibration (magnitude on the Richter scale, distance from the focus, quality of the ground, intensity on the seismic scale and so on) (See Shobo Kagabu Sogo Senta 1983). Accordingly, if the relation between housing damages and human casualties is obtained, we will be able to establish the link between the intensity of earthquakes and the scale of human casualties.

It is generally recognized that a clear correlation exists between the number (or ratio) of damaged houses and the number (or ratio) of deaths in the case of various natural hazards (Mizutani, 1983). The report presented by the Tokyo-To Bosai Kaigi (the Tokyo Metropolitan Commission for Disaster Prevention) (1978) uses, in the estimation of human casualties, the regression equation relating the number of damaged houses and the number of deaths obtained from the data on damages caused by major earthquake hazards of the past. Here we will obtain the relation between housing damages and human casualties by adding more samples from the past hazards while examining the method of dealing with the data.

First, the relation between housing damages and human casualties is obtained in the following eight cases of earthquake hazards using the data on damages that are compiled by cities, towns and villages of the prefectures shown in the parentheses: Nobi Earthquake (Aichi), Kanto Earthquake (Kanagawa), Northern Tango Earthquake (Kyoto), Northern Izu Earthquake (Shizuoka), Eastern Nankai Earthquake (Shizuoka, Aichi, Mie), Mikawa Earthquake (Aichi), Nankai Earthquake (Kochi), Fukui Earthquake (Fukui). These are samples of old-type earthquake hazards in the sense that people get injured or killed in the course where wooden houses with heavily tiled roofs collapse or burn down. That collapsing and burning-down of houses constitute a major portion of material damages still remains the case, even though nowadays we have more diversified factors of potential danger and diversified ways in which damages are done as a result of drastic qualitative changes in housing structure, life style, industrial activities, urban environment and so on. It is presumed that the intensity of damaging impact of an earthquake which operates on inhabited areas of a region is to a considerable extent reflected in the scale of damaged houses that are fixed on land; no large scale damages would ensue when intensive earthquake vibration strikes uninhabited areas. The seismic scale provided by the Meteorological Agency is based on the ratio of collapsed houses: for example, the intensity of degree 6 indicates less than 30 percent of collapsed houses, while more than 30 percent of houses would collapse with the intensity of degree 7.

The scale of housing damages is generally indicated by the weighted average of totally collapsed houses with the weight of unity and partly-collapsed houses with the weight of 0.5. In the meantime, if we are to indicate the intensity of the impact on human life, it does not seem reasonable to fix the weight attached to the partly-collapsed at 0.5; in fact almost no death arises in partly-collapsed houses due to earthquakes. A similar consideration should be given to the weight attached to burnt-down houses. A linear relation is found between the number of damaged houses and the number of deaths that are plotted against the axes with the logarithmic scale. That is, the regression equation is given by:

$$\log C = a + b \log(H_c + \quad H_p + \quad H_b)$$

where C is the number of deaths, H_c the number of the totally-collapsed, H_p the number of the partly-collapsed, and H_b the burnt-down. Here the number of partly-burnt houses is ignored since the number is very small in comparison with that of totally burnt-down houses. The above equation would be nonlinear if we made and unknown quantities to be estimated, in addition to the regression constant a and the regression coefficient b. However, our common sense suggests that the range of conceivable values of these weights would be respectively 0 to 0.5 for and 0.5 to 1.5 for . Moreover, significant figures of 1 or 2 would suffice for these values in consideration of their nature. We will obtain the weights which give us the highest correlation by assigning in sequence values which vary by the increment of 0.1 to and respectively and conducting numerous regressing analyses.

First, we obtain the weight to be attached to the partly-collapsed by running a regression using data by cities, towns and villages where no fire took place. Figure 2 shows the relation between the number of damaged houses and the number of deaths using the data on damages compiled by cities, towns and villages. As seen in the diagram, there is a large dispersion of the data points which correspond to the cities, towns and villages with a relatively small scale of damages, perhaps reflecting the increasing influence of random elements on the data. When the relation between the number of damaged houses and the number of deaths is plotted on a graph with the logarithmically scaled axes, with the weight of 0.5 provisionally attached to the partly-collapsed, we find a tendency where the dispersion grows large as the number of damaged houses, in the present case the sum of the number of the totally-collapsed and 0.5 times the number of the partly-collapsed, declines more or less below 50. We therefore exclude those cities, towns and villages with the scale of damaged houses, i.e., the number of totally-collapsed plus 0.5 times the number of the partly-collapsed, less than 50. Furthermore, when a sufficient number of data are available, we will exclude, in the subsequent regression analyses, cities, towns and villages with 5 or less deaths in some cases while 10 or less deaths in others. Meanwhile, cities, towns and villages with a relatively large scale of damages due to tsunamis are also excluded.

With these considerations we sought the weight to be attached to the partly-collapsed which generates the greatest correlation coefficient in the above eight cases of earthquake hazards, and obtained the following results: = 0 in four cases, = 0.1 in two cases, = 0.2 in one case and = 0.3 in one case. These results, however, were accompanied by small differences in the values of the correlation coefficient according to the differences in the values of . Next, we conducted regression analyses in the six cases of earthquake hazards, excluding the two cases (Kanto Earthquake and Eastern Nankai Earthquake, though a highly significant correlation was obtained) where the correlation was relatively low, and found the highest correlation when = 0.2. These results indicate that the weight attached to the partly- collapsed would be fairly small and might well be ignored for practical purposes. In reality, however, a large number of partly-collapsed houses result from an earthquake. It is thus inconsistent with the reality to ignore the partly-collapsed. We thus indicate the number of damaged houses by assigning the weight of 0.2 to the partly-cóllapsed, as was derived in the case of the six earthquakes combined. The same procedure was applied to the case of the injured and = 0.1 was obtained in the case of the six earthquakes combined. However, there is no reason for assigning a different value to the injured from that assigned to the dead. Moreover, there are very small differences in the values of the correlation coefficient according to the difference in the values of . Thus we attach the weight of 0.2 to the partly-collapsed in the case of the injured as well. Figure 3 is an example of the relation between the number of deaths and the number of damaged houses, the latter of which is indicated by the sum of the number of the totally-collapsed and 0.2 times the number of partly-collapsed.

The regression coefficients, that is, the slope of the regression line, obtained from the regression analysis described above, mostly fall into the range of 1.1 to 1.7. The value for b is 1.27 in the case of Nobi Earthquake shown in Figure 3. It is recognized in the case of wind-water hazards as well that the slope of the regression line relating the number of damaged houses and the number of deaths is slightly greater than unity. This implies that human casualties would increase not in a simple proportion but at a slightly higher rate in comparison with the rate of the increase in damaging impact which is put forth upon a certain urban area (inhabited), aggravating the damages due to the hazards.

The more leftward in the figure the regression line lies, the greater the human casualty ratio which is the number of deaths relative to the number of damaged houses. In all cases of the earthquakes, we compare the human casualty ratio using the values of the regression constant. While the regression coefficient b differs in each case of the earthquakes, it falls into the range of 1.1 to 1.7 in almost all cases. We thus remove the influence of the differences in the regression coefficient by fixing it at its median value 1.4 and obtain the value of 10^A, that is, the value of 10 raised to the power of A, which is the regression constant in the equation given by:

$$\log D = A + 1.4 \log (H_c + 0.2\ H_p)$$

where D is the number of deaths. The value thus obtained is approximately 0.007 in the following four cases of the earthquakes: Nobi, Northern Izu, Fukui and Nankai. In other words, the regression lines of these earthquakes almost coincide. By contrast, the corresponding values are 0.022 and 0.018 in the cases of Mikawa Earthquake and Northern Tango Earthquake, respectively, which indicates that the human casualty ratio is 2.5 to 3 times as high as that of the four eathquakes mentioned above.

One of the factors which presumably contributed to the higher casualty ratios in the cases of Mikawa Earthquake and Northern Tango Earthquake is that these earthquakes involved quick and severe dislocation as well as intensive vibration, which are the typical characteristics of the earthquake which takes place directly under the ground of the affected area. While factors such as time, region and season of the earthquake strike would also affect the human casualty ratio, we could not obtain quantitative estimates for the influences of these factors using the samples at hand. It should be noted in the case of Mikawa Earthquake that the human casualty ratio in fact could have been higher; the data on damages are probably poor in accuracy in consideration of the fact that the earthquake struck at the time when the country was about to lose the war (See Mochizuki et al., 1982).

Next, we use a similar method to examine the weight to be attached to burnt-down houses. In the cases of Kanto Earthquake, Northern Tango Earthquake and Fukui Earthquake, fire broke out following the earthquake in a widespread area. When we conducted regression analyses in each of these cases by assigning various weights to burnt-down houses of the cities, towns and villages where the earthquake caused fire, no significant difference in the correlation coeffcient was observed in all cases with the weight in the range of 0.5 to 1.5. One problem here is that houses which are burnt down after collapsing are generally counted as the burnt-down only but not counted as the collapsed in the statistics on damages. The statistics on damages which were brought about to the Tokyo Metropolitan Area due to Kanto Earthquake contains the number of houses which burnt-down after collapsing though the compilation was made by cities and counties. When we conducted similar regression analyses using these doubly-counted values, again no significant difference in the correlation coefficient was observed with the weight of more or less unity. The ratio of the number of deaths to the number of totally burnt houses due to fire in general is 1/13 during the decade of 1965-1974. This is very close to the ratio of the number of deaths to the number of totally-collapsed and burnt-down houses due to earthquakes, which is about 1/10. We thus found no grounds for assigning a different value than unity to the burnt-down; the weight of unity will be used for the burnt-down as well as for the totally-collapsed. Figure 2, 4 and 5 show typical examples for the relation between the number of deaths and the number of damaged houses, the latter of which is indicated by the sum of the number of the totally-collapsed, 0.2 times the number of partly-collapsed and the number of the burnt-down. A linear correlation is recognized clearly in all the figures.

2.2 Earthquake Damages in Cities

The scale of human casualties could possibly be enormous in cities. When data on damages are sorted out by the unit of cities which contain a densely-populated area of urban districts, for example, the Tokyo Meropolitan Area as a whole (without further division into wards), it would be easier to obtain the relation where the scale of human casualties would be determined according to the overall intensity of damaging impact which is put forth upon the urban area as a whole. We now choose 26 cities which suffered 10 or more deaths in the cases of the eight earthquakes mentioned earlier and earthquakes which struck Shonai, Kitatajima, Tottori, Niigata, off the coast of Tokahi and off the coast of Miyagi Prefecture (including towns with the population of ten thousand or more at the time of strike during the Meiji or Taisho Era, while these towns later became cities). Included are Tokyo, Yokohama, Yokosuka (all struck by Kanto Earthquake), Gifu (Nobi Earthquake), Tottori (Tottori Earthquake), Fukui (Fukui Earthquake), Kochi (Nankai Earthquake) and Sakata (Shoni Earthquake). Figure 6 shows the relation between the number of damaged houses and the number of deaths in the cases of earthquake hazards in these cities. The regression equation is given by:

$$\log(\text{the number of deaths}) = 1.43 + 1.12 \log(\text{totally-collapsed} + 0.2\ \text{partly-collapsed} + \text{burnt-down}) \quad (1)$$

The Cities of Niigata (Niigata Earthquake) and Sendai (the earthquake off the coast of Miyagi Prefecture) where a new aspect is prominent are excluded here; they exhibit characteristics of hazards which take place in modern cities. These cities are plotted in the figure much below the regression line. The number of deaths brought about to the Tokyo Metropolitan Area due to Kanto Earthquake includes 44 thousand deaths caused by the burst of blaze at the former clothing factory site. In the City of Tokyo the number of burnt-down houses due to the earthquake reached 290 thousand, as high as 65 percent of the entire houses of the city. When a fire of this scale spreads out throughout an urban area, there arises a possibility that a catastrophe such as that which happened at the former clothing factory site would take place somewhere in the area reflecting the impact of the overall scale of the fire. In the case when the scale of fire becomes very large, it is conceivable that the enlarged scale becomes a factor which would aggravate damages by itself. We thus obtain a multiple regression equation by taking into consideration a term indicating the scale of fire, which is added to equation (1) as:

$$\log(\text{the number of deaths}) = -1.2 + 1.5 \log(\text{totally-collapsed} + 0.2\ \text{partly-collapsed} + \text{burnt-down}) + 1.24 \times 10^{-6}\ \text{burnt-down}$$

Notice here that the term indicating the scale of fire is not expressed in terms of the logarithm so that we can use the equation even in the case with no burnt-down houses. The term indicating the scale of fire is a factor which adjusts the number of deaths progressively upwards, in other words, the conclusion of the term becomes effective as the scale of fire becomes very large. For example, while the size of this term would be 1.03 when the number of burnt-down is 10 thousand implying that the number of deaths would increase by merely three percent; it would be 2.04 when the number of the burnt-down is 250 thousand, which implies that the number of deaths would double. This is, however, the result obtained using the two sets of data from Tokyo and Yokohama (with 6.3 burnt-down houses) at the time of Kanto Earthquake.

The samples of hazards under examination are taken from those which took place in old cities. In order to link the results of the examination with prediction of the future, a term which indicates various factors of potential danger involved in modern cities would have to be added with a substantially large weight. Niigata Earthquake (the City of Niigata) and the earthquake off the coast Miyagi (the City of Sendai) are examples of hazards which took place in modern cities though the number of deaths was small in both cases. In Figure 6 these cases are plotted much below the regression line, with the number of deaths less than 1/10 of other cases. Since houses of modern cities are made of light materials, it is conjectured, the direct damaging impact on human life would be less severe even when houses are totally collapsed, in other words, when they are damaged so badly that their restoration is impossible, unlike the case when houses with heavily tiled roofs collapsed. Nine out of 32 deaths due to Niigata Earthquake and four out of 27 deaths due to the earthquake off the coast of Miyagi Prefecture were caused by collapsing of structures. Meanwhile in the case of earthquake hazards which take place in modern cities, various factors other than that which could be indicated by the number of damaged houses would be involved in the scale of damaging impact. We would have to evaluate one by one those risks involved in poisonous gas, inflammables stored in large quantities, high speed mass transportation systems, various facilities of a large size which accommodate many people and so on. To get an idea about the correlation, in the case of earthquakes which strike modern cities, between the number of deaths and the scale of damaging impact assuming that the latter could be indicated by the number of damaged houses even in the case of modern cities, we estimated the regression constant and coefficient on the basis of data from Niigata and Sendai taking into account various complex risks involved in modern cities: the regression constant turned out smaller while the regression coefficient turned out greater in comparison with earthquakes of old days. That is, the relation would be indicated by a regression line which slopes upwards at a steeper slope.

The Tokyo Bosai Kaigi (the Tokyo Metropolitan Commission for Disaster Prevention) (1978) offers a prediction that 35 thousand deaths would be caused by collapsing of wooden houses and fire in their estimation of damages which would be brought about to Tokyo if an earthquake with the intensity comparable to Kanto Earthquake struck the city. They used a regression equation relating the number of deaths with the number of damaged houses with the regression coefficient of 0.96, which is smaller than unity. It is suspected that this result is due to the fact that the regression analysis included cities, towns and villages with very small-scale damages. The result seems also affected by the fact that in the case of Kanto Earthquake the data on damages done to Tokyo were divided into wards and the lives lost at the former clothing factory site were excluded as an exceptional case. The regression coefficient of less than unity implies that the rate of increase in the number of deaths could diminish as the scale of housing damages, namely, the overall scale of damaging impact, increases. It is, however, more conceivable that the scale of human casualties woud increase at an increasing rate as the scale of damaging impact put forth upon a certain region increases, enhancing the complexity of various risks involved in the region. For example, if we consider the extent to which emergency medical teams could provide their services, the implication would be more easily understood. Therefore, it is reasonable to assign a value greater than unity to the regression coefficient as in equation (1). As for the damages to wooden structures due to an earthquake with the assumed intensity, it is estimated that the number of the totally-collapsed would be 62 thousand, that of the partly-collapsed 142 thousand and that of the burnt-down 473 thousand. Using these values the number of deaths would turn out 97 thousand under equation (1), while 245 thousand under equation (2).

Figure 7 shows the relation between the number of damaged houses and the number of the injured in the case of earthquake hazards which take place in cities. A large dispersion of data points is observed partly because we cannot expect identification of the injured to be accurately made, and partly because there is no universal standard to judge how severely a person should be injured in order to be included in statistics as the injured. It is conjectured that only severely injured persons were included in the case of such catastrophic hazards as Kanto Earthquake which struck Tokyo and Yokohama. Sendai suffered a large number of the injured when the city was struck by the earthquake off the coast of Miyagi Prefecture. More than a half of them got injured by broken glass, falling objects, collapsing furniture and so on. As there have been changes in urban environment, living style, housing structure and so on, factors which could induce injury have been multiplied in modern cities. It is conceivable that as hazards become locally amplified an increasing number of injured persons would die after being left unattended with little medical treatment.

In describing or predicting the scale of human casualties, it is sometimes convenient to use ratios instead of absolute numbers. Figure 8 shows the relation between the death rate and the ratio of the totally-collapsed plus the burnt-down in the case of earthquake hazards which take place in cities. The regression line is derived using the data from cities excluding those with a large-scale widespread fire (with 1000 or more burnt-down houses). Its slope is slightly greater than unity. In the case when a widespread fire is caused, the death rate is affected by not only the ratio of the burnt-down but also the absolute number of the burnt-down. A correlation is recognized between the intensity on the seismic scale and the ratio of the totally-collapsed. Thus data points are individually indicated by the intensity on the seismic scale. A considerable dispersion exists because a degree in the intensity on the seismic scale includes earthquakes with a fairly wide range of actual levels of intensity. Also the quality or condition of the ground would affect the result. Roughly speaking, however, the death rate would be more or less 0.01 percent in the case of the intensity of degree 5, while more or less 1 percent with the intensity of degree 6. Meanwhile, the death rate could reach 2 to 3 percent or even more if a fire with the number of burnt-down houses in the order of 100 thousand breaks out as it did in Tokyo and Yokohama in the case of Kanto Earthquake. In the figure the estimated damages are shown for reference in the case of the assumed earthquake which would strike Tokyo (with the intensity of degree 6 on the seismic scale). The death rate would be 3 percent under equation (2), while 1 percent under equation (1).

A strong correlation is recognized between the ratio of completely-destroyed houses and the death rate. In Figure 8, added are the regression lines obtained in the cases of flood plus debris-flow hazards and strong-wind plus storm-surge hazards (excluding Isewan Typhoon) which took place in cities. Since earthquake vibration and strong wind are the kind of the external force which operates globally in the operating area, they cause larger scale housing damages in comparison with flood hazards or debris-flow hazards which take place only locally in relation to the area where the external force operates. In order to compare the human casualty ratios among all three types of hazards, we obtain regression equations with the regression coefficient fixed at unity and compare the values of 10 raised to the power of a number equal to the regression constant, in other words, compare the slope of the regression lines passing through the origin when they are plotted on the graph with the ordinary scale on both axes.

3. Tsunami

Sanriku Coastal Region frequently suffers damages due to tsunamis; directly off the coast lies a trench (the Japan Trench) where large-scale earthquakes are often generated; moreover, the coast consists of rias which tend to amplify the height of tidal waves caused by earthquakes. In recent years large-scale damages were caused by 1896 Sanriku Tsunami, 1933 Sanriku Tsunami and Chile Earthquake Tsunami in 1960. In the case of 1896 Sanriku Tsunami, the two prefectures of Iwate and Miyagi suffered a devastating 25,150 deaths. While the scale of 1933 Sanriku Tsunami was comparable with that of 1896, the number of deaths was relatively smaller. Still the number reached 2935. The tsunami of 1960 was generated off the Chilean coast, traveled across the ocean for a day and a night, and struck the Japan Islands located on the opposite side of the globe. The number of deaths was 101 in the two prefectures of Iwate and Miyagi.

3.1 Relation between the Number of Damaged Houses and the Number of Deaths

Figure 9 shows the relation between the number of houses and the number of washed-away and destroyed houses by the unit of towns and villages in the case of Sanriku Tsunami Hazards in 1896. Samples are drawn from 47 towns and villages along the coast of Sanriku stretching over Iwate and Miyagi Prefectures. A highly significant correlation is recognized despite a large dispersion of data points. The ratio of the number of deaths to the number of the totally-collapsed is about 1/10 in the case of earthquake hazards. By contrast, the number of deaths was four times the number of the washed-away and destroyed in the case of the 1896 Sanriku Tsunami Hazards. The earthquake was generated, with the magnitude of 7.6 (on the Richter scale), under the sea about 200 Km east of Kamaishi at 7:33 p.m., June 15, 1896. The tsunami caused by the earthquake struck the coast of Sanriku 25 to 45 minutes later. The maximum wave height reached 32.6 m in Nemisaki of the Village of Hirota. The enormous human casualties were due partly to the fact that evacuation was not carried out promptly enough since intensive earthquake vibration was not felt on land. The 1933 tsunami was caused by a powerful earthquake with the magnitude of 8.3 (on the Richter scale) which was generated under the sea 240 Km east of Kamaishi, almost the same location as that of the tsunami in 1896, at 2:31 a.m., March 3, 1933. Intensive vibration was felt on land. The tsunami struck the coast 20 to 50 minutes later with the maximum wave height of 28.9 m in Nemisaki. While the number of washed-away and destroyed houses was almost the same as that of the 1896 tsunami, the number of deaths was about 1/9 in spite of its attack at midnight as a result of quick evacuation prompted by intensive vibration felt on land.

Figure 10 shows the relation between the number of washed-away and destroyed houses and the number of deaths in the case of the 1933 Sanriku Tsunami Hazards. While a positive correlation is recognized, there is a large dispersion of data points. This is an indication that each community had a varying degree of preparedness for disaster prevention in the sense that residentes learn from their past experience of hazards, enhance their awareness of danger and carry out quick evacuation in emergency. In the case of tsunamis, it is very effective in mitigating human casualties to evacuate quickly to a height as soon as earthquake vibration is felt or abnormal change is observed in the sea level.

Figure 11 shows the relation between the number of washed-away and destroyed houses and the number of deaths in the case of the 1896 hazards. Although the slope of the regression line is considerably greater than unity, we compare the human casualty ratio using the regression constant with the slope fixed at unity. The human casualty ratio in the case of towns and villages along the coast of Sanriku which were struck by the 1896 Sanriku Tsunami turns out 20 times that due to earthquake hazards which take place in cities. The ratio is five times greater even if it is compared with the casualty ratio in the case of cities, towns and villages located at the innermost deltaic region of Ise Bay which suffered severe damages caused by storm-surge due to Isewan Typhoon in 1959.

3.2 Factors Affecting Human Casualties

Figures 12, 13 and 14 show the changes in human casualties during the period between the 1896 hazards and the 1933 hazards in the cases of two counties of Iwate Prefecture and the coastal towns and villages of Miyagi Prefecture, respectively. Here the number of deaths, zero, cannot be shown in the figure, so the arrow is drawn intentionally in such a way that it points towards the number one. There is no town or village where the number of washed-away and destroyed houses was zero.

Major factors which would affect human casualties include timeliness and effectiveness of evacuation, an increase or a decrease in damage potential, amplification or diminution of wave height and so on. When the number of deaths declines while the number of the washed-away and destroyed remains unchanged, that is, when the arrow points downwards, the reduced number of deaths, it is interpreted, may have been brought about by evacuation (including various kinds of minor refuge in emergency). When the arrow points to a south-westerly direction, it is conceivable that diminution of the external force (wave height) or a decrease in damage potential (for example, an increasing number of houses move to highland from locations with potential danger) may contribute to the reduction in the number of casualties. If on the other hand, the intensity of the external force or the magnitude of damage potential increases, or if quick evacuation is not carried out effectively, there appears an element which points to a direction of an increase in the number of washed-away and destroyed houses or the number of deaths.

Suppose that a town or a village suffered damages indicated by point A in 1896 and those indicated by point B in 1933 in Figure 15 (coordinate axes are equidistantly scaled). Had the human casualty ratio (defined by the ratio of the number of deaths to the number of washed-away and destroyed houses) of the 1933 hazards been the same as that of the 1896 hazards, the data point for 1933 would be plotted at C which lies on the ray from the origin passing through point A. The decrement in the number of deaths which corresponds to the vertical distance DC may be regarded as attributable to the decrease in wave height or damage potential provided that the human casualty ratio remained constant at the 1896 level. On the other hand, the effect of evacuation is indicated by the vertical element AE (= CB). Thus the contribution of each factor can be evaluated by decomposing vector AB into an element parallel to the vertical axes and an element which emanates from point A and points towards the origin (it would lie on the ray from the origin with the slope of 45 degrees when plotted on the graph with the logarithmic scale). This procedure is valid even in the case when vector AB points upwards or rightwards.

We use this method to analyze the changes in the number of deaths by factors in the case of all 48 towns and villages. The overall change in the number of deaths between the year of 1896 and 1933 is -22,111, of which -21,276 is estimated to be attributable to evacuation, -5,937 to the decrease in the external force or damage potential and +4,847 to the increase in the external force or damage potential (the last figure would be +255 if we only look at those towns and villages with an increased wave height). Thus the decrement in the number of deaths is considered in most part due to the contribution of quick evacuation by residents who learned from their experience of the great hazards of the Meiji Era. Note that we assumed that breakwaters or tide-control woods which could work effectively against tsunamis of this scale did not exist.

As a whole, those towns and villages which suffered severe damages in 1896 could greatly reduce the human casualty ratio. By contrast, those with a low casualty ratio in the case of the 1896 hazards suffered an increased number or ratio of human casualties in the case of the 1933 hazards. The Villages of Sokei, Tanohata and Kuwagasaki fall into this category. In the Villages of Jugohama, Ohara and Kese, casualties increased due to a greater wave height in 1933.

In the case of Chile Earthquake Tsunami in 1960 the prefectures of Iwate and Miyagi suffered 101 deaths, most of which were caused in the City of Ofunato (53 deaths) and the Town of Shizugawa (30 deaths). Figures 12 and 14 also include the data on damages suffered by the city and the town in 1960, respectively. In Ofunato and Shizugawa damages were very slight in 1933. In particular, no death was caused in Shizugawa where the wave height was 1/3 of that in the case of the 1896 hazards. While casualties drastically declined in 1933, which is probably the reflection of the past experience, that is, the tremendous scale of casualties of the 1896 hazards gave rise to enhanced awareness of danger, the number of casualties again increased in 1960 exhibiting a V-shaped trend. Chile Earthquake Tsunami struck the region at 4:30 a.m., May 24, 1960. The overall scale of casualties was small because fishermen, who customarily woke up early in the morning and went out to beaches around 4 a.m., noticed a sign of the approaching tsunami in the abnormally ebbing tide enabling the residents to evacuate in advance. Shizugawa, however, suffered a large number of deaths due to delayed evacuation, possibly because awareness of danger was weakened by the small scale of the 1933 tsunami.

For regions where tsunamis with a great wave height are anticipated, the most effective means of disaster prevention would be community-wide transfers to higher locations. In the villages of Osawa, Otani, Funakoshi and so on, residents collectively moved up on the terrace standing behind the villages after the 1896 tsunami hazards. As a result, only a small number of people who remained at lower locations suffered from the 1933 tsunami hazards. In the village of Taro, the houses were eventually reconstructed at the same locations after the 1896 tsunami hazards though the village at first considered a community-wide transfer; the village suffered the severest damages in 1933. Collective transfers of communities to higher locations were carried out on a large scale after the 1933 hazards; a total of 3000 houses were transferred. Nowadays a number of communities located at innermost shores of bays, with low elevation, surround themselves by huge breakwaters. These breakwaters, however, become an obstacle for various daily activities such as fishing.

3.3 Relation between Tidal Wave Height and Damages

Wave height is the principal physical quantity which indicates the scale of the external force involved in tsunamis. However, the relation between the absolute number of wave height and damages is difficult to be ascertained because of differences in locations of communites, elevation and distribution of houses according to elevation. We thus obtain the ratio of wave heights in the case of the 1896 tsunami and in the case of the 1933 tsunami, and examine the relation between this ratio and damages. Figure 16 shows the relation between the tidal wave height ratio and the ratio of the numbers of the washed-away and destroyed in the corresponding two years. Tidal wave height (the average maximum sea level in the neighborhood of a community in consideration) was investigated according to communities. However, damages caused by the 1896 tsunami were only investigated according to towns and villages. So we derive the average wave height for each town and village in order to make the two sets of data consistent. In the derivation, we attach a weight to each community according to the area of that part of the community within which houses were actually washed away and destroyed. In some cases the derivation of the average wave height by the unit of towns and villages becomes difficult due to such factors as that wave height was not investigated for a considerable number of communities or that large differences in wave height exist depending on the location of the community within the bay, that is, whether located at the "mouth" or the "throat" of the bay. For those reasons, a fairly large dispersion of data points is observed. Nevertheless there is a highly significant correlation. The regression equation is given by

$$\log (H_x/H_1) = 0.357 + 1.212 \log (W_2{}^2/W_1{}^2)$$

where H_1 and W_1 are the number of washed-away and destroyed houses and wave height respectively in the case of the 1896 tsunami, and H_2 and W_2 are the number of washed-away and destroyed houses and wave height in the case of the 1933 tsunami. Here the functional form of the equation is based on the fact that energy of waves is proportional to the square of wave height. Some towns and villages have the ratio of the numbers of the washed-away and destroyed which is greater than unity though their wave height ratio is less than unity. This is presumably due to an increased damage potential (the number of houses). The village of Ohara, Kesen and Jugohama suffered from a higher wave height in 1933 (as compared with 1896): the ratio of numbers of the washed-away and destroyed suffered by these villages far exceeded unity.

Figure 16 also includes the wave height ratio and the ratio of the numbers of the washed-away and destroyed in the years of 1896 and 1933 computed for the City of Ofunato and the Town of Shizugawa both of which suffered severe damages due to Chile Earthquake Tsunami in 1960. Shizugawa is plotted almost on the regression line. Ofunato is plotted in the range fairly above the regression line with a relatively greater ratio of the numbers of the washed-away and destroyed, reflecting perhaps a greatly increased number of houses as a result of its development from a town into a city.

Figure 17 shows the relation between the ratio of the numbers of the washed-away and destroyed and the ratio of the numbers of deaths according to towns and villages. While no substantial difference in the number of washed-away and destroyed is recognized between the years of 1896 and 1933, the number of deaths in 1933 declined to about 1/9 of the 1896 level. Individual towns and villages show large differences in the degree of the decline in the number of deaths depending mainly on how they managed evacuation. Accordingly, there is a large dispersion of data points in the relation shown in Figure 17. This dispersion may give us clues for estimating the range over which values of damages could take and their upper limit.

With my best regards, I dedicate this paper to Professor Takamasa Nakano who will retire from Tokyo Metropolitan University and Center for Urban Studies in March 1984.