

# COMPARATIVE ANALYSIS OF TSUNAMI CASUALTY ESTIMATION APPROACHES

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## INTRODUCTION

Estimating the potential number of casualties resulting from a tsunami is a critical component to mitigate damage from such disasters. While agent-based models (ABMs), which can consider detailed human evacuation behavior, have increasingly been used for tsunami casualty estimations in coastal areas (e.g., Wang et al. 2022; Mostafizi et al. 2017), they require substantial computational resources and extensive preparation time. Given the challenges of deploying ABMs across widespread coastal areas at risk of tsunamis, a more simplified approach is often preferred, especially for national-level assessments (Central Disaster Management Council [CDMC] of Japan, 2013). In the simplified approach, the evacuation time is estimated using a straight-line distance from the initial position of an evacuee to the closest evacuation destination and the evacuee's moving speed (more specifically, a straight-line distance multiplied by 1.5 is often used as an effective evacuation path length). The arrival time of the tsunami at the evacuation destination is then used to assess whether an evacuee would become a casualty.

Although it is important to understand the extent of the differences between the number of casualties estimated by ABMs and those by the simplified approach, few studies have directly compared them. Notably, for the case of a near-field tsunami, the ground shaking preceding the arrival of a tsunami could lead to building collapses, generating debris that might obstruct evacuation routes. As the simplified approach does not account for the effects of such road blockage, the estimated casualty numbers could be significantly different from those estimated by the ABM, which can consider them and their subsequent impacts on evacuation behavior. However, to the best of the authors' knowledge, no existing study has compared the casualty estimates from these two approaches, taking into account building collapses and road blockages. The primary objective of the present study is thus to elucidate the discrepancies between the two approaches in estimating potential number of casualties, especially when considering road blockages. Additionally, the present study endeavored to formulate regression equations for the rapid estimation of casualty numbers.

## METHODOLOGY

Two coastal cities in Wakayama Prefecture, Japan, Mihama and Kushimoto, were selected to assess the two casualty estimation approaches in the context of a future Nankai Trough megathrust earthquake and tsunami. The present study utilized an ABM tsunami evacuation simulation model, previously developed by the authors (Takabatake et al. 2022). The model can account for various factors such as building collapses, road blockages stemming from these collapses, their subsequent impacts on evacuation behavior, and complex interactions among evacuees, including adjustments in moving speed due to road congestion. For

the simplified approach, the authors adopted the method prescribed by CDMC (2013).

In both approaches, the initial positions of evacuees, their age distribution, and the locations of the collapsed buildings and blocked roads were kept consistent. In addition, both approaches assumed that evacuees would start evacuating 5 min after the earthquake. While the ABM directed evacuees to the closest evacuation destination via the shortest route, the simplified approach assumed that they would travel along a straight line, instead of using the actual route. To adjust the discrepancies between actual distances and straight-line distances, the simplified approach multiplied straight-line distance by a factor of 1.5 (CDMC 2013). Both approaches assumed that 7% of the evacuees initially located in the collapsed buildings would become casualties (CDMC 2013). In the ABM, evacuees were also assumed to become casualties when they were caught by the tsunami during their evacuation. In contrast, the simplified approach estimated casualty numbers from tsunami inundation by simply comparing evacuation time (determined based on the adjusted distance and a moving speed) against the simulated tsunami arrival time at the evacuation destination. Furthermore, a multiple regression analysis was applied to the ABM simulation results to establish equations for quick casualty estimations.

## RESULTS

Figure 1 presents the simulated mortality rates for each scenario. In the ABM simulations, when building collapses were not considered, the mortality rates were 5.9% for Mihama and 78.8% for Kushimoto. However, when they were considered, the rates rose to 45.0% for Mihama and 87.4% for Kushimoto. On the other hand, the simplified approach estimated mortality rates of 16.3% for Mihama and 68.3% for Kushimoto without considering building collapses. The rates increased to 22.9% and 71.6%, respectively, when building collapses were considered.

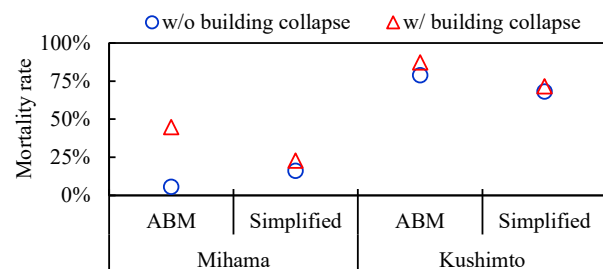


Figure 1 - Comparison of mortality rate for each simulated case

In Mihama, the mortality rate simulated by the ABM was lower than that estimated by the simplified approach when building collapses were not considered. Yet, when building collapses were considered, the mortality rate in

the ABM exceeded that of the simplified approach. In Kushimoto, the ABM consistently estimated higher mortality rates than the simplified approach, regardless of the consideration of building collapses.

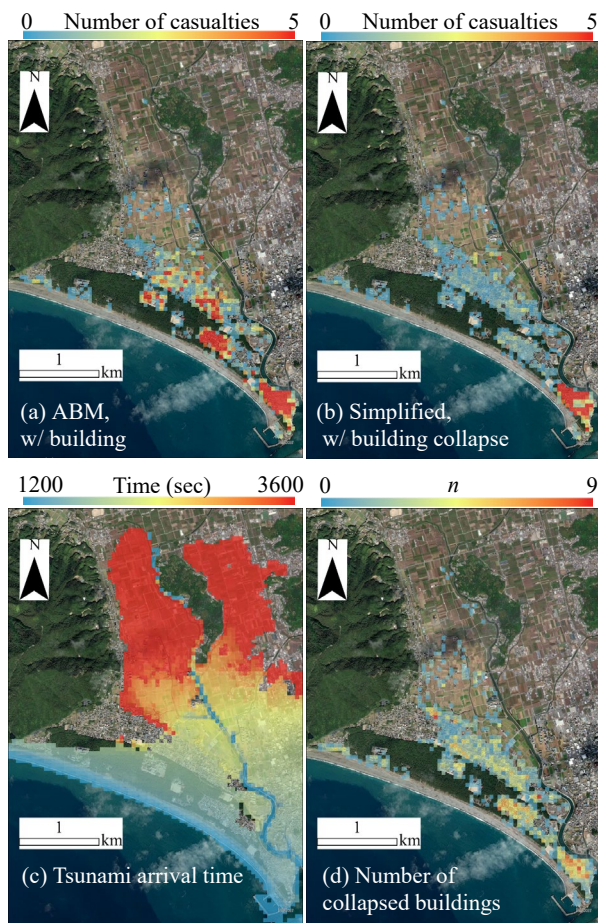


Figure 2 - Spatial distribution for Mihama (with each mesh sized at 50 m) illustrating: (a) casualty numbers estimated by the ABM, and (b) casualty numbers estimated by the simplified approach, (c) the arrival time of the tsunami, and (d) the number of collapsed buildings.

The spatial distribution of the simulated casualty numbers also demonstrated noticeable differences between the two approaches. For instance, Figures 2a and 2b show that while the southeast region of Mihama exhibited similarly higher casualty numbers in both approaches, the higher casualty numbers observed behind the coastal forests in the ABM were not properly replicated in the simplified approach. This discrepancy could be attributed to the relatively higher numbers of roads blocked due to building collapses behind the coastal forests. Since the simplified approach does not consider the effects of road blockages and the resultant route changes of evacuees, its estimated mortality rates were lower than those of the ABM, which does consider these factors.

A multiple regression analysis was then conducted, utilizing the spatial distribution of casualty numbers estimated by the ABM as dependent variables. The spatial

distribution of various parameters, such as the tsunami arrival time (Figure 2c), maximum tsunami inundation depth, the number of collapsed buildings (Figure 2d) and blocked roads, were set as independent variables. Figure 3 illustrates a comparison between the casualty numbers estimated by the ABM and those derived from the resultant regression equation. As shown, most of the plots fall within the 50% error bounds, indicating that the regression equations can estimate the number of casualties with a degree of accuracy similar to the ABM.

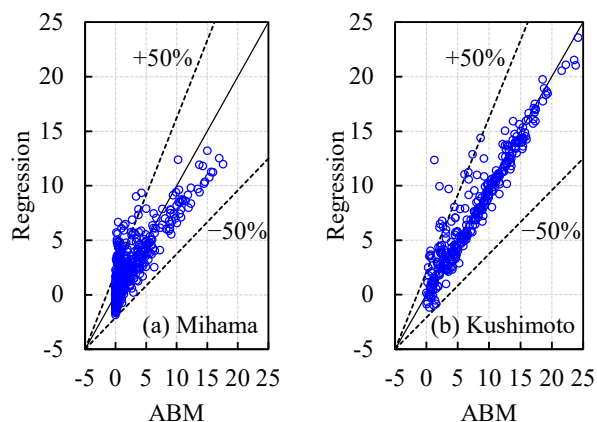


Figure 3 - Comparison of the number of casualties estimated by the ABM with those estimated by the regression equation for (a) Mihama and (b) Kushimoto.

## CONCLUSIONS

The present study revealed the significant differences in casualty estimation between the ABM and the simplified approach, particularly in the spatial distribution of the estimated casualty numbers. These findings suggest that although the simplified approach offers practical advantages, its casualty estimates would require cautious interpretation, especially in coastal areas where road blockages are anticipated to occur. Additionally, the regression equations developed in the present study were shown to be effective for the rapid casualty estimation.

## REFERENCES

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