



Technical Note

A STATISTICAL MODEL FOR ASSESSING BUILDING VULNERABILITY TO TSUNAMI IN COASTAL REGION

Ilango Sivakumar* and R. Sivagamasundari

Department of Civil and Structural Engineering, Annamalai University, Annamalaiagar-
608 002, India

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ABSTRACT

This paper aims to develop an innovative statistical model for building vulnerability of 2004 Tsunami facts provided the factors affecting it. This vulnerability is based on parameters that may cause major damages to a building after the Tsunami. In this formulation, the influencing factors are taken into account through a specifically defined combination of six parameters. In this paper, an approach called discriminant analysis is applied for assessing the vulnerability of buildings based on a combination of different factors that affect the building resistance. From the results, building vulnerability index (B.V.I) model is estimated in accordance with structures which can be a key element to preparedness. The present data is applied on the suggested model and as an output the building vulnerability is obtained.

Keywords: Tsunami; building vulnerability; vulnerability assessment; discriminant analysis.

1. INTRODUCTION

Throughout the history, Tsunamis have seriously affected many regions in the world. In particular, the past 2004 Indian Ocean Tsunami affected several countries such as India which has drawn enormous attention to the importance of studying the phenomenon in order to minimize its damages. After its passage, a Tsunami may leave behind severe losses [1]. In India severe destruction along the coast of Nagapattinam, because of its geographic setting, which has favored much inundation [2]. These losses affect different sectors such as the economic, human, social, environmental, heritage and structural sectors.

Several authors have studied these losses and in particular the associated structural damages [3-6]. The evaluation of risk due to an earthquake or a Tsunami, follows a study process which leads to scenarios and to vulnerability damage curves that are useful for the

*E-mail address of the corresponding author: isk_kpm@yahoo.com (Ilango Sivakumar)

assessment of building vulnerability [4, 7 and 8].

Tsunami building vulnerability model has been developed by using a combination of seven parameters four of which are related to the building site, while the other three parameters concern the intrinsic properties of the structure itself [9]. The Seismic Vulnerability Assessment of Existing Reinforced Concrete Buildings has been developed using discriminant analysis and GIS, Refs. [10-14].

India is a peninsular plateau and has a seacoast of about 7500 km of which the eastern coastal region is around 2700 km. Approximately 250 million people are living within the distance of 50 km towards the sea coast [15], because of which there was a great loss to human lives and properties in the 2004 Tsunami. The resettlement plan which has been implemented after 2004 Tsunami resulted ineffective in many places because the coastal community relies only upon the coastline [25]. As far, Tsunami risk and vulnerability is concerned, it is very important to develop a mitigation plan to save the coastal community. The main objective of this paper is to develop a statistical model for estimating the building vulnerability and to identify the current Building Vulnerability Index (B.V.I) to the study area.

2. DESCRIPTION OF STUDY AREA

Nagapattinam district is the worst affected area in Tamil Nadu and among the confirmed death, the Nagapattinam coast alone recorded 6065 deaths; that is equivalent to 76% of the state's total. It is also observed that the maximum run up level of sea water is 3.9 m and inundation in land is 750 m in this area [23,26]. Nearly 50% people who lost their lives in Nagapattinam district belongs to Akkaraipettai and Keechankuppam fishing villages [26,27], because of which these villages are almost like an island. The risk factor is high in this place because perpendicular evacuation is not possible during Tsunami. Hence this area is selected as the study area shown in Fig. 1.

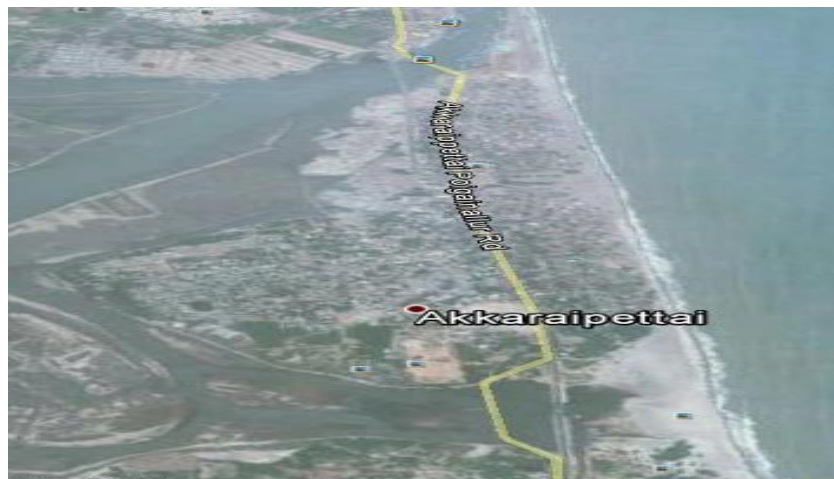


Figure 1. Study Area Map

3. IDENTIFICATION AND CLASSIFICATION OF VULNERABILITY FACTORS

Recent studies on the vulnerability assessment to Tsunamis have shown that this vulnerability is not evenly distributed within the inundation zone and depends rather on a number of parameters [16,17]. The vulnerability factors are based on recent studies of the 2004 Indian Ocean Tsunami. Following this event, it was observed that the damage level of buildings is in good correlation with the state of the buildings, construction techniques, distance from sea and height of the incoming water waves [17]. In general, these parameters vary from one research to other without a consensus. Hence in this study, the contribution of factors falls under six major parameters like building material (B.M), distance from sea (D.S), ground elevation (G.E), building condition (B.C), row position (R.P), movable object (M.O). In the analysis, for the determination of independent variables, the basic assumption made is that all the buildings in the study area are exposed to the specific 2004 Tsunami. Thus, description and scores are assigned for each parameter and presented in Table1.

Table 1.Damage Inducing Parameters

Sl. No	Variable	Values	Ordinal level	Remarks
1	Actual Assessment	Fully Damage Partially Damage	high low	Grouping variable
2	Building Material	Kutch house Semi Pucca house Pucca house	high medium low	Independent variables
3	Distance From Sea	<200m (I.Z I) 200-400m(I.Z II) >400m(I.Z III)	high medium low	Independent variables
4	Ground Elevation	<2 m 2 to 4m >4m	high medium low	Independent variables
5	Building Condition	Poor fair new	high medium low	Independent variables
6	Row Position	No barrier Fair barrier With barrier	high medium low	Independent variables
7	Movable Object	Short distance Long distance	high low	Independent variables

Source: - primary Data

However, the data acquired for building damage are retrieved from the 2004 Tsunami survey for around 365 buildings and used for developing a formulation. The building inventory was entirely formed by kutch house, semi pucca and pucca buildings. Fig. 2 shows the classification of these buildings according to the Inundation Zone (IZ). From the selected

sample full damage and partial damage with respect to inundation case is shown in Fig. 3.

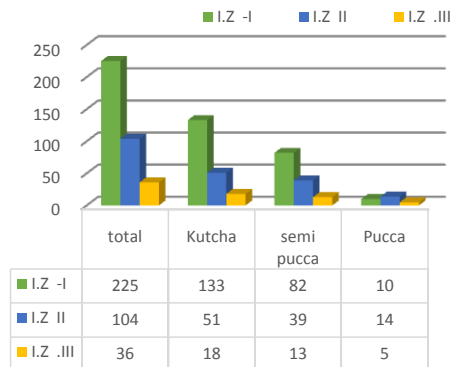


Fig. 2. Classification of buildings according to Inundation Zone

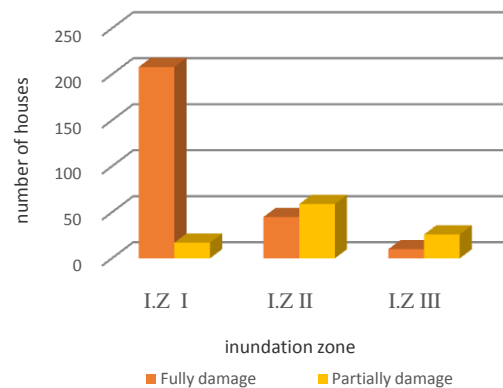


Fig. 3. Description of damages states

4. METHODOLOGY

In this study the parameters are identified and data related to building vulnerability are collected in primary forms. Subsequent scores and level of measurement are assigned for each parameter. Finally, a new model is developed and implemented for the present situation using discriminant analysis.

4.1 Data Analysis

The identified parameters provide a realistic estimation of the expected performance, if the built in structural system reflects the prescribed structural features. In general, non-engineered structures are practiced in the rural places of India, thus violating all assumptions of the usual vulnerability assessment procedures. For this reason Statistical analysis based on the observed damages and significant building attributes would provide more reliable and accurate results to perform the building vulnerability analysis. In this context, discriminant analysis technique is used for assessing building vulnerability.

Discriminant analysis is a parametric technique, which determines the weightage of quantitative variables or predictors [18,19]. This technique discriminates two or more than two groups of cases and creates a discriminant function to identify the factors that would make structures fully damage or partially damage.

In order to make a more rational and systematic evaluation of damage inducing parameters in the prediction of Tsunami vulnerability of structures, Tsunami damage to buildings is categorized into four levels, namely: light (L), moderate (M), severe (S) and collapse (C). Because of the nature of available damage data, it is necessary to combine the severe damage and collapsed states into one group, signified by fully damaged. Furthermore, if moderate and light damage states are combined into one group signified by partially damaged.

5. RESULTS AND DISCUSSIONS

Discriminant analysis is a useful procedure where in a predictive model of group is built based on the characteristics of each case. The unstandardized estimate of discriminant function based on six damage inducing parameters is obtained by utilizing the SPSS software and the database constituted after 2004 Tsunami. In this study the analysis has been carried out by the Enter Independents Together Analysis Method.

Table 2: Equality of Group Means

variables	Wilks' Lambda	F	Sig.
B.M	0.795	60.705	0.00
D.S	0.693	104.189	0.00
G.E	0.644	129.937	0.00
B.C	1.000	0.046	0.83
R.P	0.674	113.771	0.00
M.O	0.912	22.722	0.00

Table 2 provides strong statistical evidence of significant differences between means of those fully damaged or partially damaged for all factors producing high F - value but their lambda values < 1 and their significant values < 0.1. But the (B.C) have lambda value equal to one and the significant value > 0.1. So that variables does not contribute high Level in the model. Table 3 refers the discriminate function equation to identify the existing building vulnerability index as follows:

Table 3: Canonical Discriminant Function Coefficients

Variables	Function
B.M	1.134
D.S	0.430
G.E	0.742
B.C	0.187
R.P	0.468
M.O	0.097
Constant	-7.114

$$B.V.I = 1.134B.M + 0.430D.S + 0.742G.E + 0.187B.C + 0.468R.P + 0.097M.O - 7.114 \quad (1)$$

The Equation (1) can be used to generate a discriminant score for any existing building vulnerability index (B.V.I) for Tsunami. The discriminant function coefficients indicate the partial contribution of each variable to the discriminate function controlling all other variables in the equation. They provide information on the relative importance of each variable.

The result of Group Centroid by using Cutting Score Method for unequal group is -0.991. From this, if the B.V.I is <-0.991 there is a chance for the building to get partially damage and if B.V.I >-0.991 the building may undergo a full damage.

6. IMPLEMENTATION OF THE MODEL FOR THE PRESENT SITUATION

For analyzing the current building vulnerability of study area, 415 samples were selected. The details are clearly shown in Fig. 4. The recommended model is applied to the present data and as an output building vulnerability index is obtained to find out whether the building may undergo a partial or full damage.

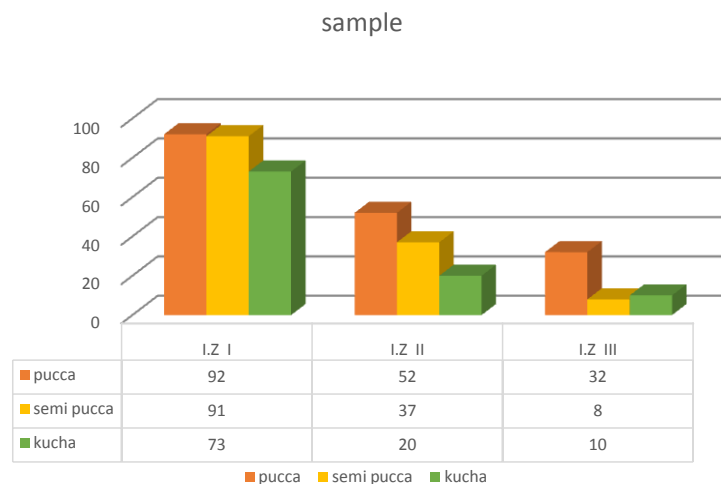


Figure 4. Sample description

The estimated building vulnerability result is shown in the table 4, the result suggests that 73% of houses may undergo a full damage in IZ-I. So, higher priority should be given for the situation in disaster pre-planning process.

Table 4: Estimated Building Vulnerability

Damage	I.Z - I	I.Z -II	I.Z - III
Full	187(73%)	33(30%)	3(6%)
Partial	69(27%)	76(70%)	47(94%)

In 2004 Tsunami, the classification rate in determining the collapsed kucha house is 75.78% and only 10.68% pucca houses were severely damaged. After 10 years, certain changes are observed in I.Z -II&-III i.e. many pucca houses are newly constructed but in I.Z -I the situation remains idle. Further it is identified that 14% of damaged structures are unconstructed after Tsunami. The recommended model is applied to the current situation and as an output building vulnerability index is obtained. The results suggest that 73% of houses

may undergo a full damage in IZ-I, (30%) in IZ II, (6%) in I.Z III and a partial damage of (27%) in IZ-I, (70%) in IZ II, (94%) in I.Z III for the selected 415 samples.

7. CONCLUSION

This discriminant analysis is used to develop a model proposed for the preliminary assessment of the Tsunami vulnerability for the devastated 365 buildings. The procedure uses discriminant analysis technique that yields discriminant functions in terms of the selected parameters. Six estimated parameters, namely building material, distance from sea, ground elevation, building condition, row position and movable object (boat), are considered for the assessment of Tsunami vulnerability. Among these parameters the building materials is found to be the most discriminating function. From the results, building vulnerability index model has been formulated. The suggested B.V.I model is applied to the current situation. As a result, 73% of houses may undergo a full damage in IZ-I, (30%) in IZ II, (6%) in I.Z III and a partial damage of (27%) in IZ-I, (70%) in IZ II, (94%) in I.Z III for the selected 415 samples. Hence the most appropriate choice to minimise the risk is constructing pucca house and the barriers. The result of this study has an important implication for many different end users, the emergency risk management, land-use planning and development, building design and construction standards. Based on the work undertaken here, a detailed assessment of the vulnerability of coastal buildings at risk areas, development of appropriate risk management strategies and a detailed program of community engagement to increase overall resilience is recommended.

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