Disaster Research as a Making Tool for Safer Building Practices

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1 THE NEED OF RESEARCH ON MITIGATION MEASURES AGAINST NATURAL DISASTERS

Natural disasters pose a growing threat to the development strategies of developing countries like Sri Lanka by destroying infrastructure and productive capacity, interrupting economic activity, and creating irreversible changes in the natural resource base. As Vermeiren (1993) says, with increasing frequency, countries are facing situations in which scarce resources that were earmarked for development projects have to be diverted to relief and reconstruction following disasters, thus setting back economic growth.

Disasters also directly impact on the foreign exchange earnings capacity of a country, at a time when extra resources are needed to finance imports of food, energy, and inputs for the agricultural and manufacturing sectors. If sustainable development is to be achieved, countries will have to take effective measures to reduce their vulnerability to natural disasters.

As a consequence, property insurance, the traditional mechanism for reducing economic risk from catastrophic events, is no longer as available or affordable as in the past. This development is now forcing property owners and developers to seriously look at other mechanisms to minimize the consequences of natural disasters. Time has come to practice disaster loss reduction in a systematic way, as an integral part of ongoing development planning and investment.

The research community has produced a vast body of knowledge on structural and non-structural mitigation measures designed to prevent or reduce the impact of natural disasters. The problem is that this information remains to a large extent within the domain of the research community and its scientific papers.

The challenge consists in translating this information into a format that can be understood by the development community, and in disseminating it to property owners, developers, and government planners.The benefits of long-term hazard mitigation go beyond economics, as the reduction in vulnerability to disasters contributes to individual security, social stability and sustainable development. Nevertheless, economic arguments built on a sound benefit-cost analysis are essential when one has to defend the use of scarce resources for investment in mitigation.
In this paper, authors wish to share some of the findings from a study conducted on tsunami reconstruction in the East Coast of Sri Lanka.

2 SIGNIFICANCE OF THIS STUDY ON TSUNAMI RECONSTRUCTION

Design of high rise buildings has followed the lateral load resistance guidelines. However, pre-tsunami domestic constructions had not been done considering the lateral load resistance guidelines. Therefore, Sri Lanka was punished badly by the nature with the devastated tsunami in 2004. These disaster damages are neither sometimes predictable nor preventable. So the only option left is to minimize the effect due to such disasters. Therefore, the designs of the structures must be capable of withstanding those natural disasters. Designers have developed a new concept called “perfect house” and they have come up with new rules and regulations for the post-tsunami construction. There are considerable amount of post-tsunami constructions already completed. It is uncertain that the newly constructed housing schemes have been designed according to the guidelines on structural aspects to mitigate damages, provided by the National Housing Development Authority Sri Lanka (NHDA-SL) and also according to the British Standard Codes. This study was basically conducted to check the behavior of the building foundations and structures which were constructed after the tsunami disaster in the East Coast of Sri Lanka.

3 TYPES OF DAMAGE OF STRUCTURES DUE TO TSUNAMI ON 26TH DECEMBER 2004

3.1 Scouring of the foundation

When running up ashore, a tsunami causes extreme rapid currents of several meters per second. Such rapid currents sometimes scour the bed around the facilities in the surrounding area; resulting in collapse and washout. Further it is evident that insufficient depth of the foundation had also become a problem for the failure of the structure. Liquefaction is also another major problem when the underneath soil strata is soft clay or loose or medium dense sand which can be easily liquefied when it is water logged. Due to the liquefaction, building foundations are treated as unsupported and hence building failures could occur.

3.2 Failure of columns

Lateral loads due to tsunami had been applied directly on the columns. Then bending effect was created on the column bases. If this bending moment is high, column can be failed easily. In many buildings, columns (mostly of reinforced concrete) failed and even collapsed due to poor quality of construction, inadequate reinforcement, or due to lack of detailing.

3.3 Failure of none engineered structures due to the lateral pressure

Proper bonds in between walls or walls and columns are very important. Then only walls can transfer lateral loads to support columns or walls. Structures can be failed by collapsing and washing away due to inadequate bond between elements due to lateral pressure exerted on walls from filled up water, uplift caused by filled up water.

3.4 Lateral bending of beams

Beams had been designed considering only the vertical bending effects. Normally reinforcements are provided to reduce the vertical bending effect. If lateral bending happens, effective length will not be sufficient to resist that moment. Therefore, beam can buckle easily. If lateral impacts react on the side of the beam, it can collapse.

3.5 Damage due to floating debris

These kinds of damages are common under cyclonic situations, tsunami and floods. Tsunami wave can hit on floating debris. Due to that strike, impact action can happen. Then structural damages might occur. If proper barrier around the building could be provided, damages can easily be reduced.

4 GUIDELINES AND THEORETICAL BACKGROUND

4.1 Guidelines proposed by National Housing Development Authority (NHDA), Sri Lanka

NHDA (2005) was in the view that the buildings in coastal belt are required a resistance against natural disasters. Therefore, Society of Structural Engineers (SSE), Sri Lanka and NHDA have jointly published “Guidelines for buildings at risk from natural disasters”. These guidelines have been developed mainly for single storey constructions and this paper discusses only the foundation construction.

4.1.1 General Principles

Columns should be connected with a concrete pad footing of minimum size 750x750x150 mm as shown in Figure 1. The columns and walls should be connected together and to ensure the frame action, the beams should be placed as shown in Figure 2.

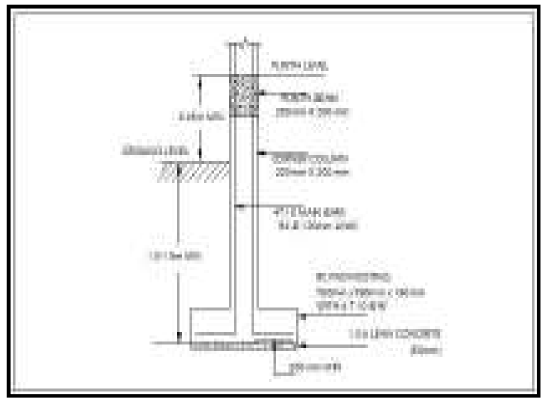

Fig01Foundation Details

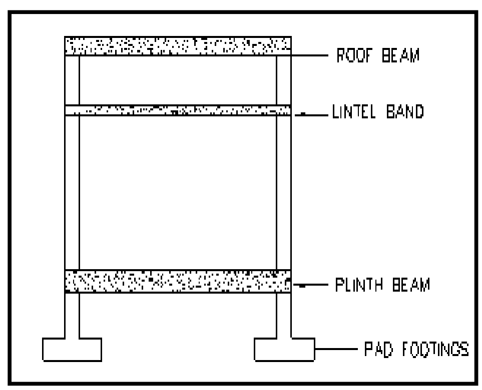

Fig 02Frame Action

4.1.2 Siting of building and planning aspects (Part 1, Guidelines for reconstruction of Houses affected by tsunami Tamilnadu- 2005)

The building should be placed in the most suitable location as possible as shown in Figure 3 and it should be oriented in such a manner that the shorter span length of the wall faces the sea as shown in Figure 4.

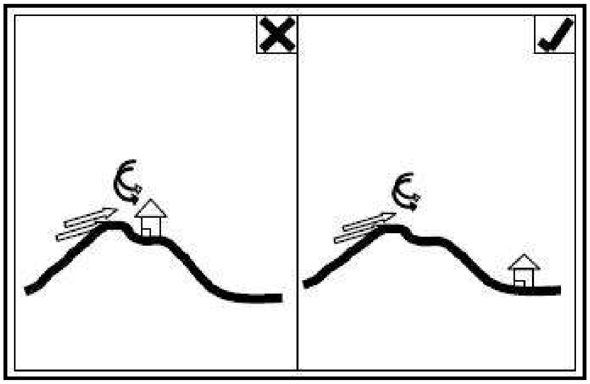

Figure 03Siting of building

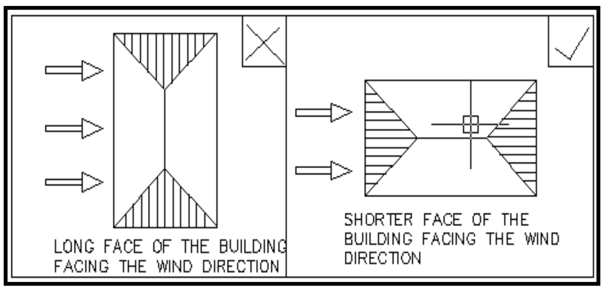

Fig 04: Orientation of building

4.1.3 Foundation

When there is a risk of scouring due to flooding a minimum foundation depth of around 1m below natural ground level should be provided in the coastal zone and foundation dimensions have been considered as shown in Figure 5.

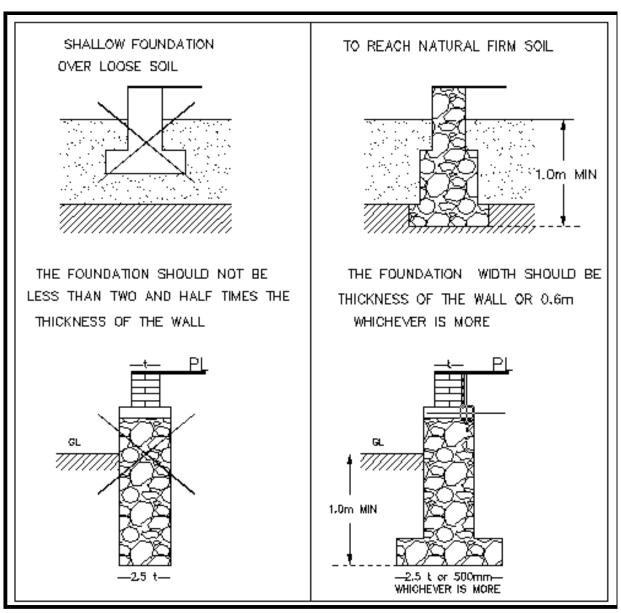

Fig 05Foundation depth and dimensions

4.2 Application of Terzaghi's Bearing Capacity Theory

4.2.1 Selection of the study area within the hazardous region

Site selection was mainly based on tsunami affected area in the buffer zone and post tsunami housing schemes in the East Coast of Sri Lanka. Two local government areas such as Marathamunai and Akkaraipattu were selected. This area had been badly affected by the tsunami and most of post tsunami housing schemes has been constructed in this area.

4.2.2 Preparation of detailed questionnaire

Detailed questionnaire was prepared based on NHDA Guideline and BS Codes. Several important factors were considered regarding the stability of them while preparing the questionnaire. The following features shown in Table 1 were observed during the survey.

4.2.3 Categorizing and analysis of data

For the analysis, collected data was summarized according to orientation of the house, foundation and superstructure. Each of data categories is needed to be summarized according to risk level. Data were collected from local authorities. 30 houses were surveyed during the survey.

Table 01Features observed during the questionnaire survey

Orientation	Foundation	Super Structure
1.Distance from the sea to location	1.Size of the pad footing	1.Size of the Columns - Below Ground
2.Ground elevation of the house (MSL +)	2.Depth of the pad footing	2.Number of columns per house
	3.Plinth beam size	3.Column Reinforcement details
3.Wall face to the sea (long wall or short wall)	4.Wall foundation depth	4.Wall thickness
	5.Wall foundation thickness	5.Opening length / Wall length ratio
	6. Type of the founding soil	6.Building sub division (land or sea side)
		7.Building (Length / Width) ratio
		8.Size of the Lintel beam
		9. Lintel Reinforcement details

5 ANALYSIS OF DATA

5.1 Data summarizing according to the NHDA guidelines

According to the NHDA guidelines, parameters were selected and three different risk levels were defined. NHDA guidelines were assigned for each parameter in Risk Level-1. Level-3 conditions were selected according to the normal practice of construction of domestic houses. Then the moderate conditions were applied according to Level-1 and Level-3 value conditions to define the Level-2.Table 3 gives the basic details as different risk levels.

For the purpose of analysis, three levels were defined for each set of parameter. For each structure, those parts were considered separately. As an example for a building, a level was given for its foundation, superstructure and orientation of buildings. Then the mentioned structure has three pre-defined risk level values. Then structure is evaluated entirely by observing the levels by the three major set of parameters for the relevant natural disaster. Then risk level of each structure part was defined according to the risk level.

Table 02Assigned risk level conditions

Parameter	**Level -1**	**Level -2**	**Level -3**
Orientation			
Distance from sea(m)	>200	60-200	<60(minimum distance)
Ground elevation(MSL+)	>3	3-1	<1
Wall face to sea(Long/Short)	Short	Long	Long
Foundation			
Size(Pad footing)	>750X750X150	600X600X100	<500X500X100
Depth	>1000	1000-500	<500
Plinth size	>200X200	150X150	Not Provided
Wall foundation depth	>1000	1000-300	<300
Wall foundation thickness	>550	550-300	<300
Soil type	Clay	Dense sand	Loose sand
Super Structure			
Column-below ground	>200X200	200X100	<100X100
Column-above ground	>150X150	150X100	Not provided
Number of column	>4	<4	Not provided
Column Reinforcement	4Y10	4Y10	-

Wall thickness	Hollow	>200	>200	>200
	Solid	>125	>125	>125
Opening length/Wall length		<0.5	0.5-0.75	>0.75
Building Length/Width		<3	3-5	>5
Lintel		>200X100 Band	100X100	Not provided
Lintel Reinforcement		>2Y10	>2R10	-
Roof Beam		>200X200	150X150	Not provided
Roof Beam Reinforcement		>4Y10		
Roof fastening with SS		Provided	Not provided	Not provided

5.2 Defined level of risk for each houses

According to the engineering knowledge and experience, overall risk can be evaluated by studying their levels and other features. The variation of overall risk with respect to the orientation, foundation level and super structure level is described in Table 3.

5.3 Analysis According to Terazaghi's bearing capacity theory

Factor of safety (FoS) values were calculated using net ultimate capacity and the available structural load. Table 4 shows these FoS values and their corresponding risk levels for 30 different post tsunami houses constructed in the so-called buffer zone.

Table 03Overall risk definition

Orientation	Foundation	Superstructure	Overall risk
Level-1	Level-1	Level-1	Low
Level-2	Level-1	Level-1	Low
Level-3	Level-1	Level-1	Moderate
Level-1	Level-2	Level-1	Low
Level-2	Level-2	Level-1	Moderate
Level-3	Level-2	Level-1	High
Level-1	Level-3	Level-1	Moderate
Level-2	Level-3	Level-1	High
Level-3	Level-3	Level-1	High
Level-1	Level-1	Level-2	Low
Level-2	Level-1	Level-2	Moderate
Level-3	Level-1	Level-2	Moderate
Level-1	Level-2	Level-2	Moderate
Level-2	Level-2	Level-2	High
Level-3	Level-2	Level-2	High
Level-1	Level-3	Level-2	High
Level-2	Level-3	Level-2	High
Level-3	Level-3	Level-2	High

***If superstructure in level-3, directly it falls into High risk level*

Table 04Categorized result of both methods in one table

House Index	**Orientation**	**Foundation**	**Superstructure**	**Risk level**	q_f	**FoS**
1	Level-2	Level-2	Level-2	Moderate	1445.85	3.29
2	Level-2	Level-1	Level-1	Low	2567.97	6.03

3	Level-3	Level-1	Level-2	Moderate	700.18	8.77
4	Level-2	Level-1	Level-1	Low	280.31	7.18
5	Level-2	Level-1	Level-1	Low	3286.26	7.68
6	Level-1	Level-2	Level-2	Moderate	1980.98	4.54
7	Level-3	Level-1	Level-2	Moderate	279.49	1.13
8	Level-2	Level-3	Level-1	High	1496.39	3.40
9	Level-1	Level-1	Level-2	Low	613.43	7.30
10	Level-1	Level-2	Level-1	Low	1701.11	3.89
11	Level-1	Level-1	Level-1	Low	626.80	7.54
12	Level-1	Level-3	Level-2	High	1077.71	2.42
13	Level-1	Level-3	Level-1	Moderate	1440.18	3.24
14	Level-2	Level-1	Level-1	Low	277.86	1.12
15	Level-2	Level-1	Leve-2	Moderate	277.86	1.12
16	Level-2	Level-3	Level-2	High	1291.67	2.92
17	Level-2	Level-1	Level-1	Low	760.15	9.84
18	Level-2	Level-1	Level-2	Moderate	632.16	7.67
19	Level-1	Level-1	Level-1	Low	279.20	1.13
20	Level-2	Level-1	Level-2	Moderate	714.76	8.79
21	Level-2	Level-1	Level-1	Low	3405.71	7.93
22	Level-1	Level-3	Level-2	High	1116.53	2.51
23	Level-1	Level-1	Level-2	Low	586.74	6.86
24	Level-3	Level-2	Level-2	High	2011.32	4.60
25	Level-2	Level-2	Level-2	High	1701.11	3.89
26	Level-1	Level-3	Level-2	High	1291.67	2.92
27	Level-1	Level-1	Level-1	Low	279.49	1.13
28	Level-1	Level-1	Level-1	Low	2488.24	5.78
29	Level-3	Level-1	Level-2	Moderate	281.12	1.14
30	Level-1	Level-1	Level-2	Low	280.31	1.13

5.4 Results and summary

FoS values greater than 3.0 are considered as low or moderate risk houses while those FoS are less than 3.0 are treated as high risk houses.

Table 05Results and discussion

Risk Condition	NHDA	Terzaghi
Low risk houses	46.66%	FoS≥3, 70%
Moderate risk houses	30.00%	
High risk houses	23.33%	FoS<3, 30%

Results are very interestingly shown that both methods have nearly similar percentage for high risk houses. NHDA Analysis was done in according to engineering knowledge and practice. Analysis of the other method was done according to FoS defined by Terzaghi. In this method of analysis, effect of water table has also been considered. High risk houses could be completely destroyed at a future tsunami. Therefore, those house holders must pay attention to the tsunami risk warnings. Moderate risk houses can have partial structural damages.

6 RECOMMENDATIONS

According to the analysis, some houses can be classified as high risk. Therefore, it is essential to get proper decisions in order to improve strength of each house. Especially, high risk houses will be completely damaged under future tsunami waves. At least, it requires saving human life by providing them the safer locations during a natural disaster.

6.1 *In General*

Breakwaters can be arranged around the sea side of the village. It can reduce speed of the flood wave. It was understood that the importance of placing huge boulders along the coast line, to protect shore line. Further, vegetation can reduce the propagating of wave energy.

6.2 *Planning stage*

1. Openings in general are areas of weakness and stress concentration, but are needed for lighting and ventilation. The openings should be avoided in walls facing the sea.
2. Having more openings in the direction parallel to wave direction will lead to diagonal tension failure. Therefore openings should be minimized effectively.
3. The buildings should be oriented in such a manner that the shorter span length of the wall faces the sea. That will minimize the loads acting on the building due to wind and tsunami.

6.3 *Foundation*

1. When there is risk of scouring due to wave action (in loose sand or medium dense sand) a minimum foundation depth of around 1m below natural ground level and minimum of 1m x 1m footing should be provided in the coastal zone.
2. In grounds with loose sand, soil can be improved by mixing with granular material before starting the construction. That will avoid the liquefaction of sandy soil during tsunamis. Heavy tamping may also be considered as a viable solution before construction commences.
3. Common constructions using foundation materials such as the random rubble masonry is not capable of resisting tensile force of significant magnitude that may be generated in an earthquake. Thus, the foundation should be provided with tie beams.

7 CONCLUSIONS

During this research, mainly tsunami incident was focused to observe the behavior of houses against any future tsunami. However, other natural disasters also can make this type of damage for the domestic constructions. However, it is the coastal belt that can be mainly affected due to a tsunami. Therefore, domestic constructions were evaluated by collecting data from Marathamuna and Akkaraipattu area using two analyzing methods. Method-1 was taken as the methodology proposed by NHDA-SL and Method-2 was done considering Terzaghi's bearing capacity theory. Approximate decision on different risk levels could be established. According to the first methods, 46.6% houses are in low risk level, 30.00% houses are in moderate risk level and 23.33% houses are in high risk level. High risk houses can be completely damaged under tsunami waves. During the questionnaire survey it was found that the most of house owners are not aware on housing and structural details. Some values were put based on reasonable assumptions. Orientation of the building was selected according to the direction of the sea. However the actual situation may be different because these buildings might be covered by another house or boundary wall in the fence during a future construction activity. Orientation of the building is not important in at that type of places.

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