FIRE EVACUATION SAFETY ANALYSIS OF TYPICAL HIGH-RISE BUILDINGS IN BANGLADESH

-An Analysis based on lessons learnt from Japan Fire Incidents and concerned rules and regulations applying to building plans of Bangladesh-

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1. Introduction:

1.1 Evacuation Safety in High-rise Building

Fire safety of high-rise buildings has been a special concern for as long as there been high-rise buildings. Evacuation safety issues in high-rise building fire attracted attention due many fatalities in the world.

Urban building fire issue in Bangladesh is considered as one of the common problems. In 2001 the total number of fire incidents in Bangladesh was 6,051 which reached up to 12,182 in 2009 that reflects the super increasing rate of fire incidents i.e. almost double in 2009. The trend of building fire shows that the number of building fire is almost 60-70% of the total fire in Bangladesh (figure:01).

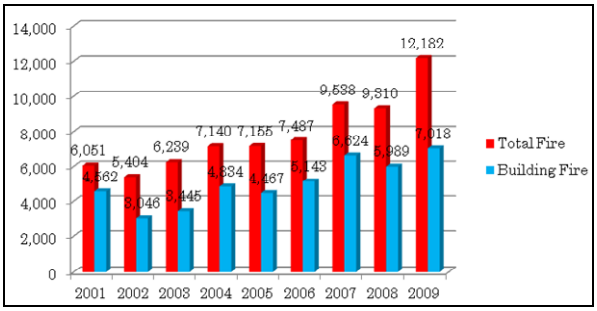

Figure: 01: Total Fire & Building Fire in Bangladesh

As per the statistics of Fire Service White Paper in Japan, 2010 Edition, the main cause of the fire deaths is failing to escape which is 55.8% of total death. From 2005 to 2009, almost 30% people died due to CO poisoning/suffocation in Japan. These also indicate the importance of evacuation safety. This study focused on the various aspects of evacuation safety of high-rise buildings.

1.2 Purpose of Study:

The main purpose of this study was to address the main problems of evacuation safety of high-rise buildings in Bangladesh. It is an analysis of lessons learnt from Japan's past building fire incidents and concerned rules and regulations applying on the existing building plans of Bangladesh.

2. Data Collection

To do the analysis of evacuation safety of high-rise buildings, 1) 35 major past building fire incidents report of Japan, 2) building construction related rules and regulations of Japan and Bangladesh, 3) 30 different occupancies high-rise building plans of Bangladesh, were collected.

3. Methodology:

3.1 35 major past building fire incident reports of Japan from 1932 to 1990 were analyzed to address the main problems of fatalities and the changes of laws and regulations related to evacuation safety.

3.2 The rules and regulations related to evacuation safety in fire of Japan and Bangladesh were also analyzed to highlight the important differences between these two laws which might have great impact on the evacuation safety.

3.3 30 high-rise building plans of different occupancies in Bangladesh were reviewed to address the common problems of evacuation safety of those building plans specially in the building design perspectives.

3.4 Fire room and fire floor evacuation of 04 high-rise building plans of Bangladesh were evaluated as a case study using the performance based verification methods: calculation method and Fire Escape Simulator, to evaluate the fire evacuation safety.

4. Analysis Results:

4.1 Analysis of Past Major Building Fire Incidents in Japan

Due to the economic revolution, rapid urbanization, industrialization in the first decade of the 20th century, Japan experienced several building fire incidents which caused massive fatalities. Though fire resistive buildings were begun to be constructed at the first decade of 20th century, the fatalities did not decrease apparently. Therefore, there were continuous analysis of the causes of fatalities by the concerned government organizations and subsequently the building construction related rules and regulations were amended time to time to cope with the problems. In this regard, 35 past major building fire incidents were analyzed to address the trend of problems concerning evacuation safety and the amendment of rules and regulation.

The analysis showed that there were several problems of evacuation safety in the high-rise building fire incidents and Lack of Fire Compartmentation was the most common problems among all (Figure: 02).

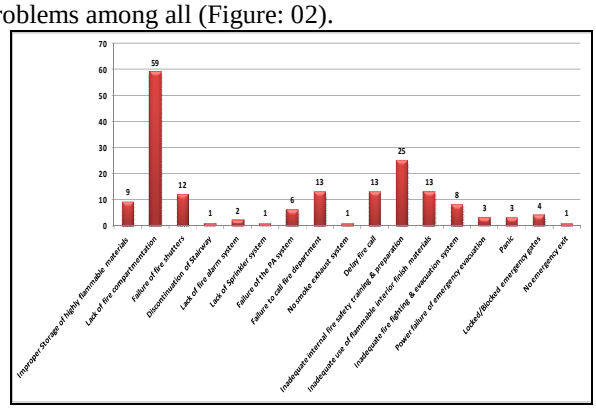

Figure: 02: Trends of Main Problems of Evacuation Safety

The further analysis of the lack of fire compartmentation which had 59 cases was done and it includes the following problems of evacuation safety (Figure: 03):

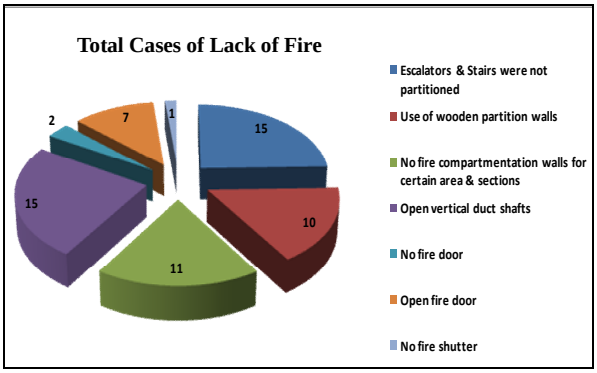

Figure: 03: Problems of Lack of Fire Compartmentation

The analysis revealed that the Building Standard Law (BSL) of Japan was introduced in 1950 from the update of traditional Urban District Building Law (UDBL) which was based on Uniform Building Code (UBC) of US. The most significant factor of this revision of the BSL is to design the law in the context of the scenarios of building fires in Japan based on the ongoing investigation and analysis of the building fire incidents in Japan.

After 1950, to cope with the increasing number of fatal building fire incidents, there were continuous amendment of BSL and Fire Service Law (FSL) in Japan based on the analysis of the fire incidents which were found effective. The major amendments of BSL are: fire compartmentation for specific floor area and pipe and duct shafts, provision of fire retardant, quasi fire retardant and non combustible materials, standard for the use of interior finish material, specific guidelines for specific occupancies such as hotel, hospital/nursing home, department store, multi-tenant building, and underground shopping mall, The major amendments of FSL are: specification for the installation of sprinkler and detector, organization of building's self fire fighting team, inspection and maintenance of building fire fighting facilities, strengthen of administrative law for judicial steps against negligence or abandonment of fire safety arrangement, provision of labeling "Teki" as compliance of fire safety regulations.

The experience from the analysis and investigation of past building fire incidents were being used to update and amend the concerned rules and regulations which had great impact to improve the building evacuation safety.

Though the BSL was amended time to time, it was a big challenge to implement the rules to the existing old buildings since it was only applicable to the new buildings. Because it was practically difficult to implement on the existing structural part of the buildings. Thus, FSL standard was strengthened which was comparatively easier to implement. It was a very effective alternate way to strengthen the evacuation safety systems in the buildings.

The amendment of rules and the compliance of rules were found effective and thus fire deaths is some specific occupancies such as restaurants, department stores, hospitals, warehouse facilities were gradually decreased though fire deaths did not reduce in office, multipurpose use and residential buildings (Figure: 04)

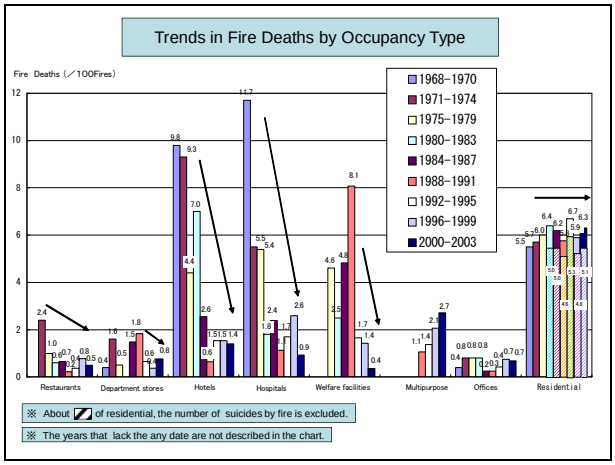

Figure: 04: Trends of Fire Deaths by Occupancy Type

4.2 Comparison of Building Construction related Rules and Regulations of Japan and Bangladesh

Comparison of rules and regulation related to building codes of Japan and Bangladesh reveals some similarities and differences. The considerations of bed movement for the width of corridor in the hospital, occupancy load for number of exits, specific requirement for specific occupancies, specific requirement for high-rise building etc. in Bangladesh National Building Code (BNBC) of Bangladesh are very important for the evacuation safety.

The considerations of interior finish material and floor height to reduce/increase the traveling distance to the exit, fire walls in wooden building and fire compartmentation for specific area for specific floor etc. are also very important for the evacuation safety. These important factors play important role to improve the evacuation safety in the high-rise buildings.

4.3 Review of Evacuation Safety Problems in 30 Building Plans of Bangladesh

30 high-rise building plans of Bangladesh were reviewed following the BSL of Japan, Bangladesh National Building Code (BNBC) of Bangladesh and generally practiced principles regarding evacuation safety to address the common problems (Figure 05).

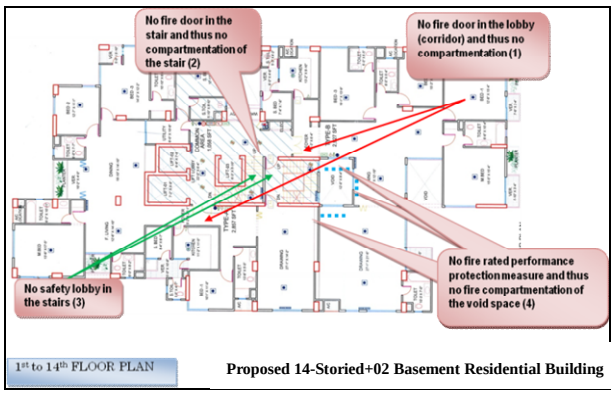

Figure: 05: Model Case Study of Review of Building Plan

This analysis revealed that there were several common problems of evacuation safety in the building design plans and risky fire compartmentation is one of the most common problems among all (Figure: 06):

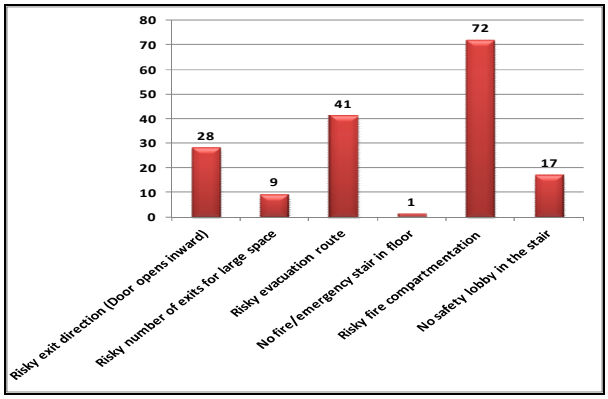

Figure: 06: Trends of Main Problems of Evacuation Safety

Further analysis of the lack of fire compartmentation and risky evacuation route which had 72 & 41 cases respectively was done and those include the following problems of evacuation safety (Figure: 07 & 08):

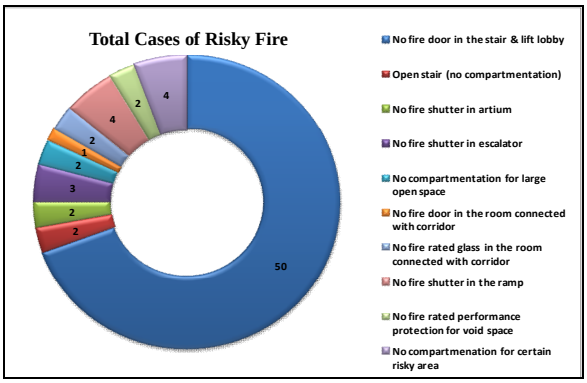

Figure: 07: Problems of Risky Fire Compartmentation

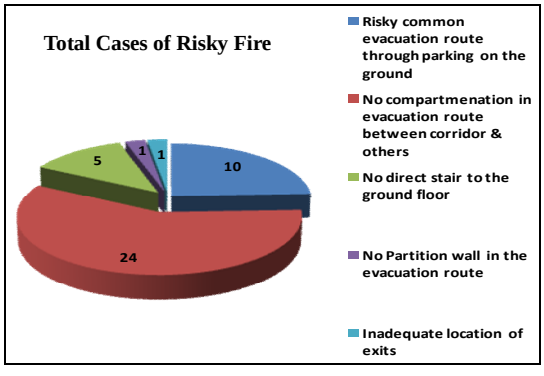

Figure: 08: Problems of Risky Fire Evacuation Route

4.4 Case Studies for Verification of Fire Room and Fire Floor Evacuation Safety of 04 Different Occupancies High-rise Building Plans of Bangladesh

4.4.1 Verification of Fire Room and Fire Floor Evacuation Safety using Calculation Method

As case studies, fire room and fire floor evacuation safety of 04 different occupancies high-rise building plans were evaluated using the performance based verification method; calculation method following the Article 129-2 of The Building Standard Law Enforcement Order of Japan and the Notification No. 1440 & 1441 of the Ministry of Construction/May 31, 2000 of Japan. As per these rules, the governing equations for this verification were as follows:

For Fire Room Evacuation:

$$t_{start} = \frac{\sqrt{\sum A_{area}}}{30}, \quad t_{travel} = \max\left(\sum \frac{l_l}{v}\right), \quad t_{queue} = \frac{\sum pA_{area}}{\sum N_{eff} B_{eff}}$$

$$t_s = \frac{A_{room} \times (H_{room} - 1.8)}{\max(V_s - V_{e,} 0.01)}$$

Here,

t_{start} = time required in the habitable room to start to evacuate (min.)

t_{travel} = traveling time that occupants require to go from each part of the said habitable room, etc. to an exit (min.)

t_{queue} = time required to pass through the exit or exits of the said habitable room (min.)

t_s = time required for smoke or gas produced by a fire occurring in the said habitable room to descend to a level that obstructs evacuation (min.)

If the time required for the evacuation of the fire room i.e. is mor$(t_{start} + t_{travel} + t_{queue})$ ired for the smoke and gas layer to descend in the fire room i.e. (t_s), the fire room evacuation by the occupants will be considered as risky.

For Fire Floor Evacuation:

$$t_{start} = \frac{\sqrt{A_{floor}}}{30} + 5 \text{ or } \frac{\sqrt{A_{floor}}}{30} + 3, \quad t_{travel} = \max\left(\sum \frac{l_l}{v}\right),$$

$$t_{queue} = \frac{\sum pA_{area}}{N_{eff} B_{st}}, \quad t_s = \frac{A_{room} \times (H_{room} - H_{\lim})}{\max(V_s - V_{e,} 0.01)}$$

Here,

t_{start} = time required in the floor to start to evacuate (min.)

t_{travel} = traveling time required in the floor to go from each part of each room etc. of the said floor to one of the through stairs (min.)

t_{queue} = time required for occupants in the floor to pass through the exit to the through stairs from the said floor (min.)

t_s = floor smoke filling time (unit: min.) calculated for each room on the floor

If the time required for the evacuation of the fire floor i.e. is mor$(t_{start} + t_{travel} + t_{queue})$ ired for the smoke and gas layer to descend in the fire floor i.e. (t_s), the fire floor evacuation by the occupants will be considered as risky.

A summary of results of the verification of fire room and fire floor evacuation safety of 04 high-rise building plans of Bangladesh is as below (Table: 01):

Table: 01: Verification Results of Room and Floor Evacuation Safety using Calculation Method

Case Study/ Building Information	Time Required for		Safe/Unsafe Room Evacuation	Time Required for		Safe/Unsafe Floor Evacuation
	Fire Room Evacuation	Smoke and Gas Layer to descend to a level that would obstruct the safe room evacuation		Fire Floor Evacuation	Smoke and Gas Layer to descend to a level that would obstruct the safe floor evacuation	
Case Study-1 09 Storied Residential Building	0.52 min	0.19 min	Unsafe Room Evacuation	6.3 min	27.38 min	Safe Floor Evacuation
Case Study-2 14 Storied Commercial Building	1.60 min	0.67 min	Unsafe Room Evacuation	4.37 min	27.72 min	Safe Floor Evacuation
Case Study-3 10 Storied Industrial Building	1.87 min	0.91 min	Unsafe Room Evacuation	4.54 min	1.19 min	Unsafe Floor Evacuation
Case Study-4 14 Storied Commercial Building	1.24 min	1.06 min	Unsafe Room Evacuation	1.24 min	1.06 min	Unsafe Floor Evacuation

The results showed that all 04 building plans are unsafe for fire room evacuation where as 02 building plans are fully unsafe for fire room and fire floor evacuation and 02 plans are partially safe for floor evacuation. The possible reasons for the unsafe room evacuation might be the inadequate number of exits and for unsafe floor evacuation might be lack of compartmentation in the stair and corridor. These case studies reflect the evacuation safety conditions of high-rise buildings in Bangladesh specially in the design phase. The

4.4.2 Verification of Fire Floor Evacuation Safety applying Fire Escape Simulator

As case studies, fire floor evacuation safety of 04 different occupancies high-rise building plans were also evaluated applying Fire Escape Simulator of Japan (EVATUS). EVATUS was developed at Tokyo University of Science. The features of this simulator are as follows:

- Prediction of evacuation behavior based on the potential hazard method that enables analysis of **user-defined** architectural space.
- Modeling of evacuation behavior in building with the prediction of **evacuee behavior in congested situations** based on participant experiments.
- Coupling with the smoke movement analysis code, BRI2COE that enables inclusion of the **effect of spreading smoke on evacuees** and the **effect of evacuation behavior on smoke propagation through the doorway**.

This simulator can simulate various evacuation safety factors such as: initiation time of evacuation, completion time of evacuation, smoke descent time, heat release rate, fire growth rate etc. based on input information (Figure: 09 & Figure: 10)

The results showed that all 04 building plans are unsafe for floor evacuation because some persons in all floors may not be able to secure safe evacuation passage.

The main purpose of these case studies was to understand the condition of evacuation safety of high-rise buildings in Bangladesh specially in the design phase. Both verification results showed that building designs are not safe for evacuation safety.

A summary of results of the verification of fire floor evacuation safety is as below (Table: 02):

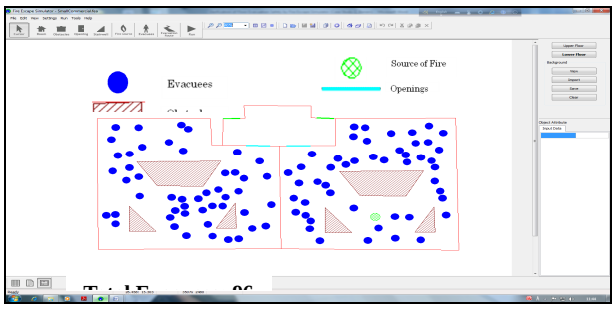

Figure: 09: Model Case Study by Fire Escape Simulator (EVATUS)

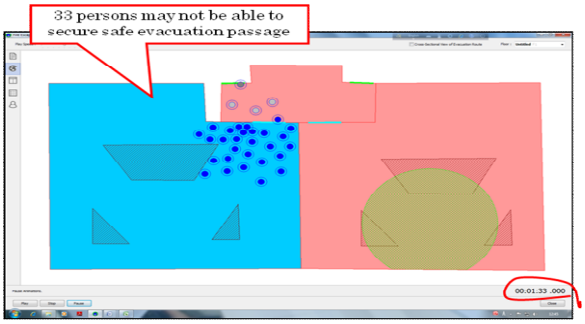

Figure: 10: Model Case Study by Fire Escape Simulator (EVATUS)

Table: 02: Verification Results of Floor Evacuation Safety

Case Study/ Building Information			Safe/Unsafe Floor Evacuation
	Total Number of Evacuees	Number of People who may not be able to secure safe evacuation passage	
Case Study-1 09 Storied Residential Building	29 persons	13 persons	Unsafe Floor Evacuation
Case Study-2 14 Storied Commercial Building	96 persons	33 persons	Unsafe Floor Evacuation
Case Study-3 10 Storied Industrial Building	57 persons	01 person	Unsafe Floor Evacuation
Case Study-4 14 Storied Commercial Building	95 persons	03 persons	Unsafe Floor Evacuation

5. Conclusions

This study focused on various aspects of evacuation safety of high-rise buildings in Bangladesh. This study indicates lack/risky fire compartmentation was one of the most common problems of the evacuation safety in both the past building fire incidents in Japan and in the review of 30 building plans in Bangladesh. These lack/risky fire compartmentation include mainly the lack of compartmentation in the vertical shafts such as: staircase, escalator, atrium, duct shaft etc. which can cause rapid smoke propagation and thus the emergency evacuation would be hampered in case of fire. Therefore, the building fire safety design should be given due importance by the architects/designers and other concerned parties.

To cope with the increasing number of fatal building fire incidents, there was continuous amendment of BSL FSL in Japan based on the analysis of the fire incidents which were found effective.

Comparison of rules and regulations of Japan and Bangladesh reveals the important aspects of evacuation safety which might be considered during the update of building codes in Bangladesh.

The results of case studies of verifications of room and floor evacuation safety of high-rise building plans of Bangladesh were shown unsafe. These kinds of performance based verification methods might be included in the update of BNBC in Bangladesh in near future.

This study results might be used as a tool by the concerned professionals and authorities for future improvement of evacuation safety not only in Japan and Bangladesh but also anywhere in the world following the local context.