

## **An Investigation of Recent Building Collapses around the World with Special References to Rana Plaza**

R. Islam<sup>1</sup>, M. A. K. Azad<sup>2</sup>, A. Sinha<sup>3</sup> and M. Lixon<sup>4</sup>

*Every year a large number of buildings collapse around the world. It is important to investigate the reasons for collapse because a large number of people are killed or injured. In this thesis the Rana Plaza Building (the largest disaster occurred on 24 April 2013 at Savar, Dhaka, Bangladesh) collapsed has been broadly discussed because it was one of the biggest non-terror-related structure failure where 1,135 people were killed and 2,515 were injured. Before the analysis of the Rana Plaza some of the recent building failures around the world have been analyzed. These include Ronan Point collapse, Hyatt Regency walkway collapse, World Trade Centre collapse and Sampoong department store collapse. In this thesis the causes of these four major failures have been identified and discussed. We have analyzed the Rana Plaza by Etabs using as-built condition and from the analysis we have shown that the structure was already in vulnerable position and the generator just triggered the failure.*

**Keywords:** Collapse, Faulty Design, Poor Material, Public Awareness.

**Field of Research:** Civil Engineering

### **1. Introduction:**

Buildings are structures that serve as shelters for man, his properties and activities. They must be properly planned, designed and constructed to obtain desired satisfaction from the environment. The factors to be observed in building construction include durability, adequate stability to prevent its failure or discomfort to the users, resistance to weather, fire outbreak and other forms of accidents. The need to build structure with integrity goes back as far as recorded history. Houses needed to be able to support their own weight, plus the weight of the inhabitants. Castles needed to be fortified to withstand assaults from invaders. Tools also needed to be strong and tough enough to do their jobs. However, it was not until the 1920s that the science of fracture, namely the brittleness of glass, was described by Alan Arnold Griffith. Even so, a real need for the science did not present itself until World War II, when over 200 welded-steel ships broke in half due to brittle fracture, caused by a combination of the stresses created from the welding process, temperature changes, and the stress points created at the square corners of the bulkheads. After then, the growing sizes of bridges and buildings began to lead to even greater catastrophes and loss of life. In this paper, section 1 deals with 'Introduction', section 2 deals with 'Literature Review', section 3 deals with 'Methodology'. Also section 4 deals with 'Result & Discussion', section 5 & section 6 deals with 'Conclusion & References' respectively.

<sup>1</sup> Rubinoor Islam, Lecturer, Department of Civil Engineering, European University of Bangladesh, email address: [rubinoorce20@gmail.com](mailto:rubinoorce20@gmail.com)

<sup>2</sup> Dr. Md. Abulkalam Azad, Associate Professor, Department of Civil Engineering, European University of Bangladesh, email address: [dmakazad17@gmail.com](mailto:dmakazad17@gmail.com)

<sup>3</sup> Abdullah Sinha, Graduated student, Department of Civil Engineering, University of Asia Pacific, [tanvirsinha007@yahoo.com](mailto:tanvirsinha007@yahoo.com)

<sup>4</sup> Md. Lixon, Graduated student, Department of Civil Engineering, University of Asia Pacific, [lixon.uap@gmail.com](mailto:lixon.uap@gmail.com)

## **2. Literature Review:**

When a building collapsed, devastating effects are felt more painfully by the inhabitants than the owner. Poor structural design, use of substandard building materials, non-compliance with approved building design, poor workmanship, and lack of qualified and cost control among others are the main causes of building failures in all over the world. Major structural failures of buildings around the world are currently well known to everyone because many are described in the print media. These failures become known to the public, because someone is killed or seriously hurt, not just to discredit the structural engineer, the builder and the other professionals involved in the case of the collapsed buildings. This research examines the cases of a collapsed building with special reference to Rana Plaza that was under construction in Savar, Bangladesh. On 24 April 2013, Rana Plaza, an eight-storied commercial building, collapsed in Savar, a sub-district in the Greater Dhaka Area, the capital of Bangladesh. The search for the dead ended on 13 May with the death toll of 1,129. Around 2,515 victims were saved from the building alive. It is considered to be the deadliest garment-factory accident in history, as well as the deadliest accidental structural failure in modern human history.

On Wednesday morning there was a power cut and diesel generators on the top floor were started. The building collapsed at about 08:57am leaving only the ground floor intact. The Bangladesh Garment Manufacturers and Exporters Association president confirmed that 3,122 workers were in the building at the time of the collapse. One local resident described the scene as if "an earthquake had struck."

## **3. Methodology:**

### **3.1 Building Description:**

The location of Rana Plaza Building was at Savar Bazar Bus stand, Savar, Dhaka. It was a ten storied building including one basement. It was Reinforced Cement Concrete Frame Structure 108 ft height above plinth. The Architecture and consultancy of Rana Plaza were done by Architects of Vaastukalpa (up to 5<sup>th</sup> Floor). The Structural Engineer was Engr. Sajjad Hossain, IEB M-1016380 and Rajuk E-00152. The building work was done by Sohel Rana owner of Rana Plaza. The opening year of Rana plaza was 2010 without complete it.

### **3.2 Approval of the Building:**

The approval of the building was done by two stages. **In First Stage**, it was shown that the basement of the building was used for car parking, level 1 to 3 used as shops and 4 to 6 as office. There were two architectural drawing sheets containing floor plan, section and elevation. No structural drawings and soil investigation report were found in Pourashabha office. **In Second Stage**, it was shown that the basement of the building was used for car parking, level 1 to 3 used as shops and 4 to 10 as office. There were three architectural drawing sheets containing floor plan, section and elevation. Two structural drawing sheets found in Pourashabha office.

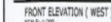


Fig: Semi basement, 1<sup>st</sup>, 2<sup>nd</sup> floor plan and section( from approved drawing 2006)

### 3.3 Structural Assessment:

### Assessment Criteria Considered (Stage1: for Seven Story)

|                                  |  |
|----------------------------------|--|
| Compressive Strength of Concrete | $f'_c=2,500$ psi with brick chips  |
| Rebar Yield Strength             | $f_y=60,000$ psi   |
| Dead load                        | Slab 6" =75 psf , Floor finish=25 psf<br>Partition wall=40 psf (shop), 20 psf (office)         |
| Live load                        | For shop=80 psf, for office=60psf  |
| Wind Load                        | 210 Km/hr ( For Dhaka)   |
| Earthquake Load                  | $z=0.15$ As per BNBC-93  |
| Column Size                      | 20"X20" in Basement<br>18"X18" in Ground & First floor levels<br>15"X15" in rest of Top levels |
| Beam Size                        | 20"X30"/20"X20"/12"X20"  |
| Analysis Method                  | 3-D finite element analysis  |
| Software Used                    | ETABS Nonlinear Version 9.7.1  |

### 3.4 Construction and Quality Control:

There was no working structural drawing was available. Design concrete strength  $f'_c$  and steel strength  $f_y$  was not specified in the submitted structural design. Brick chips were used as coarse aggregate. Test of construction materials (rebar, cement, concrete etc.) was never done. Work progress was never submitted to Pourashabha authority. The construction sequence/ method were faulty. There was absence of proper detailing.

#### 3.4.1 Test Report for Compressive Strength of Concrete of Rana Plaza:

| <b>HOUSING &amp; BUILDING RESEARCH INSTITUTE</b><br>Building Materials Division<br>Darus-Salam, Mirpur, Dhaka-1216 |                            |   |                                      |                      |                  |                               |                               |         |
|--|----------------------------|---|--------------------------------------|----------------------|------------------|-------------------------------|-------------------------------|---------|
| TEST REPORT  |                            |   |                                      |                      |                  |                               |                               |         |
| Sample   |                            | কর্ডকট (সাকার রানা প্লাজার ধনসোপেশ থেকে সংগ্রহকৃত) : (ASTM-C42) |                                      |                      |                  |                               |                               |         |
| Source   |                            |   |                                      |                      |                  |                               |                               |         |
| Memo/Ref. No.  |                            | 05.41.2600.002.10.010.13-764                                    |                                      |                      | Date: 04-05-2013 |                               |                               |         |
| Sl. No.  | Identification Mark        | Date of Sample Collection                                       | *Cylindrical Concrete Core Size (mm) | Date of Core Cutting | Date of Testing  | Compressive Strength in (PSI) | Compressive Strength in (MPa) | Remarks |
| 08.  | Beam Level-2, M-1,3        | 09/05/2013  | 75 × 38                              | 14/05/2013           | 14/05/2013       | 1515.25                       | 10.45                         |         |
| 09.  | Beam Level-2, M-1,3        | 09/05/2013  | 75 × 38                              | 14/05/2013           | 14/05/2013       | 1597.90                       | 11.02                         |         |
| 10.  | Slab Level-3, I-1,2, J-1,2 | 09/05/2013  | 75 × 38                              | 14/05/2013           | 14/05/2013       | 1270.20                       | 8.76                          |         |
| 11.  | Column Level-2, M-1        | 09/05/2013  | 75 × 38                              | 14/05/2013           | 14/05/2013       | 1661.70                       | 11.46                         |         |
| 12.  | Beam Level-2, M-1          | 09/05/2013  | 75 × 38                              | 14/05/2013           | 14/05/2013       | 1468.85                       | 10.13                         |         |
| 13.  | Beam Level-3, K-1,3        | 09/05/2013  | 75 × 38                              | 14/05/2013           | 14/05/2013       | 2131.50                       | 14.70                         |         |
| 14.  | Beam Level-3, K-1,2        | 09/05/2013  | 75 × 38                              | 14/05/2013           | 14/05/2013       | 2059.00                       | 14.20                         |         |

\* Block sample collected from the field (Rana Plaza) and core cutting done in the laboratory.

**Tested by:**  
Md. Zakir Hossain  
Research Associate  
Housing & Building Research Institute  
Darus Salam Mirpur, Dhaka.

**Verified by:**  
(স্বাক্ষরিত করেছেন স্বাক্ষর)  
Housing & Building Research Institute  
Darus Salam Mirpur, Dhaka.

**Section-in-Charge**  
Senior Research Officer  
Physical Testing Research Laboratory  
Housing & Building Research Institute

#### 3.4.2 Test Report for Tensile Strength of Reinforcement Bar of Rana Plaza:

| <b>HOUSING &amp; BUILDING RESEARCH INSTITUTE</b><br>Building Materials Division<br>Darus-Salam, Mirpur, Dhaka-1216 |                           |   |                   |                  |                                |                                       |                         |                                    |
|--|---------------------------|---|-------------------|------------------|--------------------------------|---------------------------------------|-------------------------|------------------------------------|
| TEST REPORT  |                           |   |                   |                  |                                |                                       |                         |                                    |
| Sample   |                           | Deformed Bar (সাকার রানা প্লাজার ধনসোপেশ থেকে সংগ্রহকৃত) : (ASTM A 370) |                   |                  |                                |                                       |                         |                                    |
| Source   |                           |   |                   |                  |                                |                                       |                         |                                    |
| Memo/Ref. No.  |                           | 05.41.2600.002.10.010.13-764  |                   |                  | Date: 04-05-2013               |                                       |                         |                                    |
| Specimen No.   | Date of Sample Collection | Identification Mark   | Nominal dia in mm | Actual Dia in mm | Actual Area in cm <sup>2</sup> | Elongation (%) (Gauge length=203.2mm) | Yield Strength in (MPa) | Ultimate Tensile Strength in (MPa) |
| 1.   | 08/05/2013                | Column, Level-4, M-2  | 22                | 21.80            | 3.73                           | 7.50                                  | 323.14                  | 461.63                             |
| 2.   | 08/05/2013                | Column, Level-4, M-2  | 22                | 21.82            | 3.74                           | 12.50                                 | 321.30                  | 459.00                             |
| 3.   | 09/05/2013                | Column, Level-2, M-2  | 22                | 21.75            | 3.72                           | 17.50                                 | 328.41                  | 469.16                             |
| 4.   | 09/05/2013                | Column, Level-2, M-2  | 22                | 21.80            | 3.73                           | 13.75                                 | 329.56                  | 470.81                             |
| 5.   | 08/05/2013                | Column, Level-4, M-2  | 22                | 21.82            | 3.74                           | 12.50                                 | 321.30                  | 459.00                             |
| 6.   | 08/05/2013                | Column, Level-2, M-2  | 22                | 21.75            | 3.72                           | 17.50                                 | 328.41                  | 469.16                             |
| 7.   | 08/05/2013                | Column, Level-2, M-2  | 22                | 21.80            | 3.73                           | 13.75                                 | 329.56                  | 470.81                             |
| 8.   | 08/05/2013                | Column, Level-3, D-6  | 20                | 18.75            | 2.76                           | 18.75                                 | 275.52                  | 393.60                             |
| 9.   | 08/05/2013                | Column, Level-3, D-6  | 20                | 18.90            | 2.81                           | 6.25                                  | 262.19                  | 374.55                             |
| 10.  | 09/05/2013                | Column, Level-1, N-1  | 16                | 15.80            | 1.96                           | 3.12                                  | 425.59                  | 607.91                             |
| 11.  | 09/05/2013                | Column, Level-1, N-1  | 16                | 15.70            | 1.94                           | 12.50                                 | 456.98                  | 652.86                             |
| 12.  | 08/05/2013                | Column, Level-3, N-1  | 16                | 15.85            | 1.97                           | 13.20                                 | 352.34                  | 530.46                             |
| 13.  | 09/05/2013                | Beam, Level-1, L-8,10   | 16                | 15.68            | 1.93                           | 20.00                                 | 320.93                  | 458.48                             |
| 14.  | 09/05/2013                | Beam, Level-1, L-8,10   | 16                | 15.68            | 1.93                           | 25.00                                 | 343.86                  | 458.48                             |
| 15.  | 08/05/2013                | Beam, Level-4, G-2,6  | 16                | 15.66            | 1.93                           | 17.50                                 | 362.79                  | 518.28                             |

### 3.5 Analysis of Rana Plaza by Etabs:

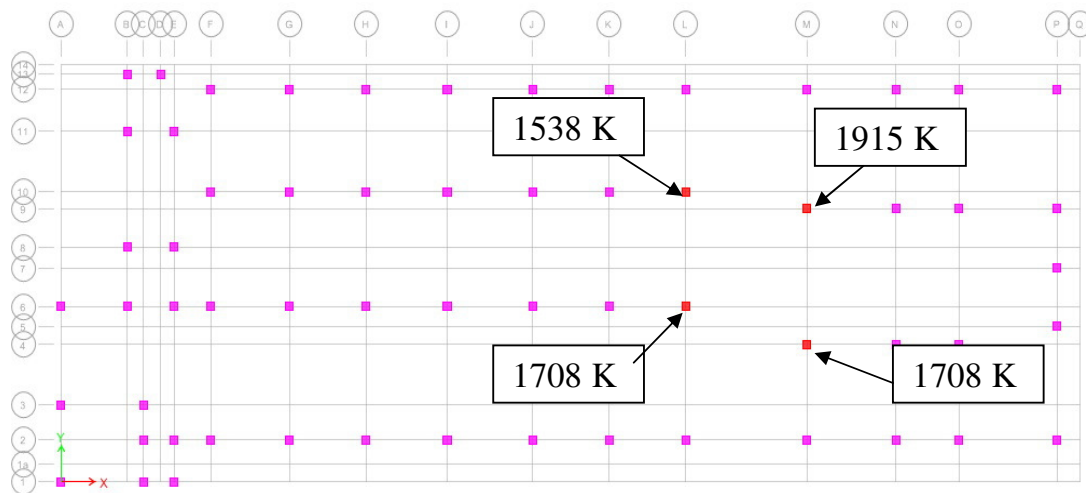
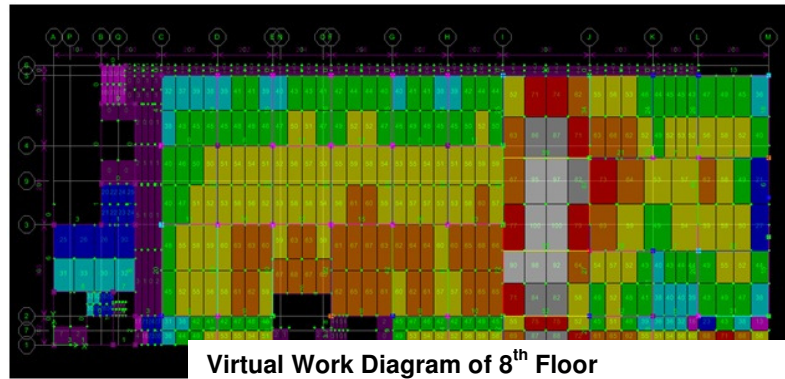
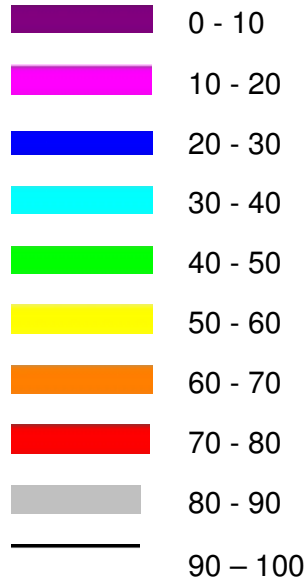
#### Virtual Work Diagram:

Virtual Work Diagram command to display energy diagrams that can be used as an aid to determine which elements should be stiffened to most efficiently control the lateral displacements of a structure. **For showing** Energy/Virtual Work Diagram we



have to select a load case associated with forces and one associated with displacements from the drop-down boxes.

These colors represent which elements should be stiffened to control lateral displacements in structure.



Overstressed Column at Basement Floor

## 4. Result and Discussion:

### 4.1 Comparisons between Four Building Collapses:

The reason of *Ronan Point* collapse was initiated by improper maintenance of leaked gas pipes. The failure of the single panel caused one entire corner of the building to collapse because there was insufficient reinforcement steel passing between the panels and also the loads carried by the panel could not be redistributed to other adjacent panels, because there was no alternate route for the forces to follow. From all investigations it was seen that Ronan Point apartment tower was deeply flawed in

both design and construction and in designing it, the existing building codes were not maintained appropriately.

In the investigation of *Hyatt Regency Walkway* collapse it was found that, the connection of rod hanger which carrying the 4th floor walkway pulled through the box beams was failed because the contractor modified the design detail to use 2 hanger rods instead of one and the engineer approved the design change without checking it. It was also seen that the nut of the box beam which supported the weight of 2 walkways instead of one.

From the investigations of FEMA and NIST, it was found that the initial impact on *Twin Tower* due to the airplanes destroyed a number of the perimeter columns, floor joists and core columns. When the steel was unprotected and heated beyond 1,500 degrees Fahrenheit, the steel began to weaken and soften. Then the structure failed.

The main reasons of *Sampoong Department store* collapse were poorly-laid foundation & unstable ground, substandard concrete mix with sea water and poor reinforcement. In the designing of it, the required columns size was 80cm in diameter where 60 cm was used and the number of steel reinforcing bars into the concrete was 8, not the required 16. The another reason was the corruption and lack of supervision of Authorities.

#### **4.2 Summary of Findings:**

The building was never approvable. Because the name on the design of Engineer and Architect is not exists. There was no provision for verification and approval of structural design by approving authority (SavarPourashabha). Structural design was faulty and inadequate. The whole structural irregularity was due to faulty architectural design. The construction was done by the owner not engineered construction. There was no use of standard material. Also there were so many changes of occupancy by owner without design checking. Administrative failure was to prevent use of the building despite of getting advance signs and symptoms of collapse. Rana Plaza had some design inadequacy from the very beginning. The building was approved for two times and there were some faults during construction. From the ETABS analysis of Rana Plaza the energy diagram shows that the building was in danger position due to its static loads only. Some of the sections were needed to be stiffer by increasing the section. In a government investigation, it was shown that properties of concrete and other materials was much poor. Modulus of elasticity was near about 1500 ksi and for steel it varied for each and every section in a big scale.

#### **5. Conclusion**

The main causes of failure of *Hyatt Regency Walkway* and *Sampoong Department store* were change of design without further checking of adequacy. In addition, the main causes of failure of *Ronan Point* and *Twin Tower* were the impact loads. From *Rana plaza* analysis by ETABS for static load we found that the structure was in danger position due to its static load only. So, it can be said that the preliminary crack was occurred due to static loads but the final failure was initiated by generator vibration. The building was stable for three years with these static loads because of its factor of safety.

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