Management of Building Collapse in Nigeria: A Lesson from Earthquake-Triggered Building Collapse in Athens, Greece

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Abstract

Recent scientific outputs most especially those published by the Nigerian Building and Road Research Institute (NBRRT) have drawn the attentions of researchers and Nigerian government to the myriad of building collapse and a need for the development of realistic and sustainable approach for the management of building collapse in Nigeria. Since then, a number of different explanations of how and why buildings collapsed in Nigeria have appeared. However, none of these have adequately focused on the most important issue, namely 'what structural mechanisms led to the state which triggered the collapse'. In this paper, a case study of structural failure in the European monumental city of Athens where European model for the management of building collapse is fully implemented is considered. Structural Analysis Program (SAP) and pi-Design were used for the aseismic investigation and retrofits of the building. The result obtained from the analysis showed that the reduction in the stiffness and resulting friction of the ground floor slabs, and the load bearing columns were the main causes of the building collapse. The European methodology for the management of building collapse proved efficient. It provides the basis for developing countries to develop their own models for the management of building collapse.

Keywords: Management, building collapse, structural mechanisms, aseismic investigation, retrofits, stiffness, friction

1. Introduction

Over the last 10 years, the incidence of building collapse in Nigeria has become so alarming and does not show any sign of abating. Each collapse carries along with it tremendous effects that cannot be easily forgotten by any of its victim. These include loss of human lives, economic wastage in terms of loss of properties, jobs, incomes, loss of trust, dignity and exasperation of crises among the stake holders and environmental disaster (Ede 2010).

On the 11th of August 2010, thirteen people died in a building, which collapsed at Ikole Street, Abuja, while about 35 persons are believed to be trapped in the debris while 10 persons were rescued (Bukola 2010 cited in Ede 2010). Five (5) storey hotel collapses at Adenubi Close Ikeja, Lagos and the 2-Storey Zenith bank building collapse at Mararaba on the outskirts of Abuja are cases of building collapse that occurred in the first half of 2011 in Nigeria. Another case of building collapse (5-storey structure with a Pent-house located at 11 Aderibigbe Street, Maryland, Lagos) was also recorded in October, 2011 (NBRRI 2011). Elsewhere in the United States, a New York City contractor was cited on Monday by federal authorities, who said it did not ensure that a Brooklyn building under construction was stable before it collapsed in November 2011, killing a worker and injuring four others (The New York Times 2012). Wednesday night's collapse highlights the creaky infrastructure of the city that will host the 2014 soccer World Cup and the 2016 Olympics. The buildings, one 20 floors high, collapsed in a cloud of dust behind the city's 100-year-old Belle Epoque-style Municipal Theater (China Daily 2012).

Ayininuola & Olalusi (2004) opined that every built structure is expected to satisfy the functional objectives of safety, serviceability, and economy. The processes of construction are complex and require the services of trained professionals. They further noted that a high level of skill is needed both in designing and construction. In his research titled "Structural Stability in Nigeria and Worsening Environmental Disorder: The Way Forward" Ede (2010) noted that every structural system is designed to meet some needs and be safe to avoid loss of life, property, and damage to the environment. In a normal set up, failures are not expected within the projected lifespan of structures. But due to the imperfection in the actions of human beings and the existence of so many other external factors that influence the safety of structures, failures do occur. He also observed that the factors responsible for building collapse are complex but a well-structured model designed for the management of building collapse can give a more realistic prediction of those ones responsible for the collapse.

In a special report tagged "Why Building Collapse in Nigeria" NBRRI in May 2012 concluded that while providing suggestions and solutions to the basic problem of building collapse, all professionals and academics

must also look at associated and allied issues and disciplines that actually complicate the problem.
In Europe, the response to structural failure involves five major steps:

- Physical inspection of the affected structure for first-hand information.
- Thorough study of the structural drawings and other relevant documents.
- Modelling and analyses of the structure in order to determine the exact causes of the failure.
- Geotechnical Investigation.
- Decision(s) on the required interventions.

This approach designed for the management of building collapse has been successfully implemented with valid conclusions.

After series of investigations, the causes of Cologne's City archive building was discovered. Cologne's City archive building had not been underpinned or compensation grouted despite its proximity to the underground works being carried out for the Cologne North-South light railway, a Cologne transit authority Kölner Verkehrs-Betriebe (KVB) spokesman revealed today (Rowson 2009). Usmani *et al.* (2004) in their article titled: How Did the WTC Towers Collapse: A New Theory, used a finite element model to investigate the stability of the Twin-Towers of the World Trade Center, New York for a number of different fire scenario without taking the structural damage caused by the terrorist attack into consideration. They concluded that that the collapse was initiated principally by a stability mechanism as a result of geometry changes in the structure caused by thermal expansion effects.

In this study, aseismic investigation and retrofits of a collapsed residential building in the Olympic city of Athens in considered. Its aim is to investigate the causes of the collapse and provide mechanism(s) for strengthening the earthquake affected building with the aid of finite element programs-SAP and pi-DESIGN. Figure 1.0 show the ground floor plan produced with pi-DESIGN.

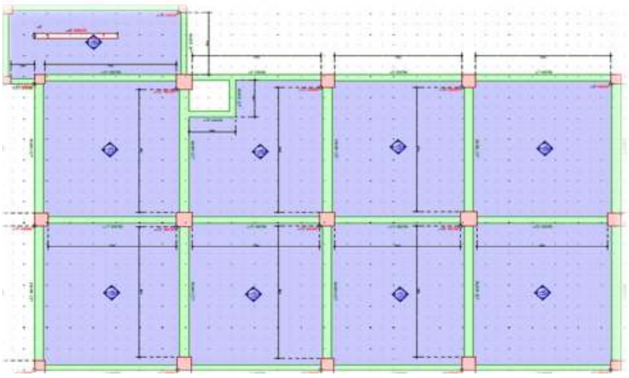

Figure 1. The Ground Floor Plan of the Building

2. Methodology

2.1 Preparation of the Model

Having thoroughly studied the working drawings of the collapsed building, we decided to come up with a model. The model of the structure was prepared with the aid of finite element program-SAP using the working drawings and the structural details of the structure.

The finite element models of the structure under investigation are shown in Figure 2 and 3 respectively.

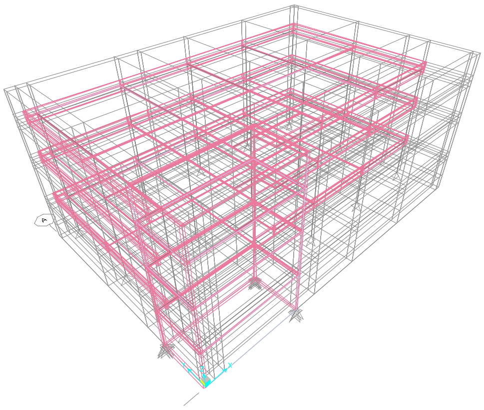

Figure 2. The Finite Element Model: Line Model

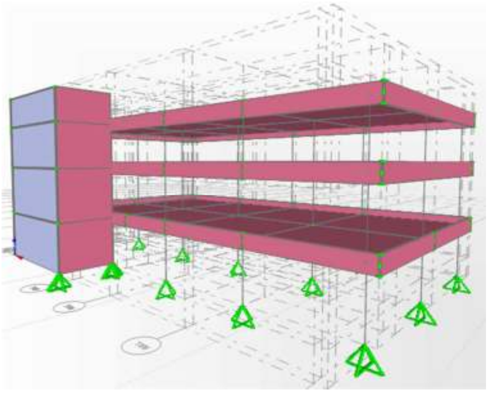

Figure 3. The Finite Element Model: Body Model

Figure 4 and 5 shows different views of the final model of the structure.

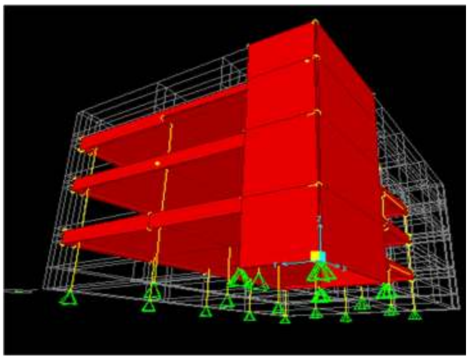

Figure 4. The Final Model showing

Fixed Joint Restraints

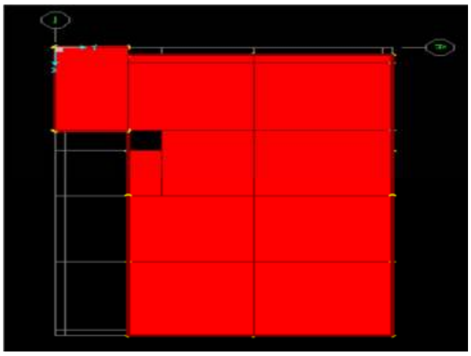

Figure 5. The Plan View of the Model

2.2 Analysis of the Model before Strengthening

Dynamic analyses were carried out using the model and excitation parameters. A dead load of 74.025kPa and live load of 18.50kPa were imposed on the structure as joint loads. Two types of analysis were performed - Modal-Time History and Modal-Response Spectrum analyses.

2.2.1 Modal-Time History Analysis

For the modal load case type, the following parameters were set:

Type of vector: Ritz vector, Maximum number of modes: 12, Minimum number of modes: 1, and Load type: Acceleration

For the time history load case type, the following parameters were set:

Analysis type: Linear, Time history type: Modal, Load type: Acceleration, and Modal damping: 5%

Function: The sine

The sin function entails the following parameters:

Period: 1s, Number of steps per cycle: 20, Number of cycle: 5, and Amplitude: 2

2.2.2 Modal-Response Spectrum Analysis

The modal load case type parameters are the same as in the case of Modal-Time History.

For Eurocode 8-2004 response spectrum function, the following parameters were set:

Design ground acceleration, Ag = 0.24

Spectrum type: 1, Ground type: B, Behaviour factor: 1, and Function damping ratio: 5%

2.3 Design Interventions (Strengthening Solutions)

In order to strengthen the structure, we decided to increase the stiffness of the basement by adding shear walls in the longitudinal and transverse directions. Figure 6 shows the positions of the shear walls in the structure. In addition, aluminium rods (see Figure 7) were used to secure the slab frames to the structure. It was introduced in order to connect and make the building act as a system.

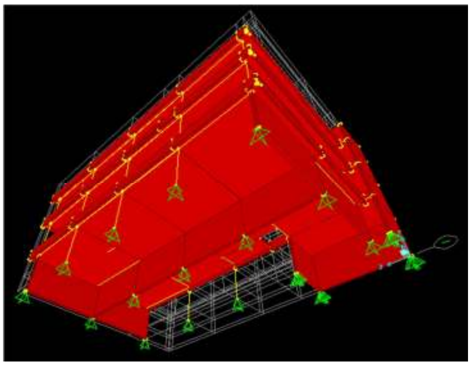

Figure 6. Positions of the Shear Walls

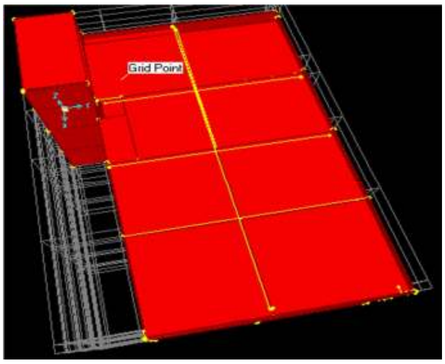

Figure 7. Positions of the Aluminium Bars

2.4 Analyses of the Model after Strengthening

The modal analyses were performed using the same parameters as in the case of the structure analysed before strengthening.

3. Results and Discussion

3.1 Analysis of the Model before Strengthening

The results of the structural analysis are presented here in form of pictures.

DEFORMED SHAPE

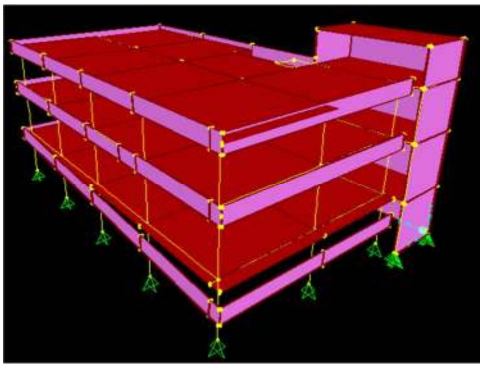

Figure 8. Deformed Shape of the Model

The deformed shape of the model corresponds to the exact mode of failure of the real structure and the deformation is the same as the one observed in the real structure.

VULNERABLE AREAS

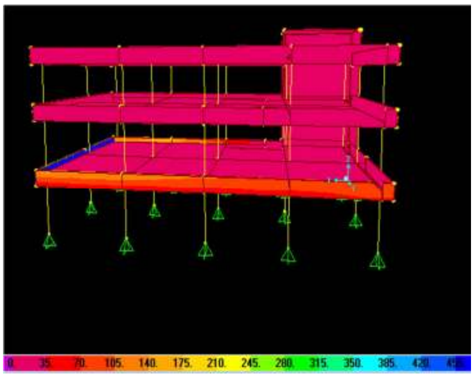

Figure 9. Stress SMAX distribution in the Structure

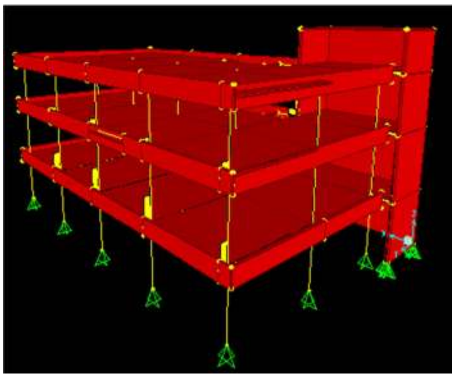

Figure 10. Torsional Force distribution in the Structure

The results from Figure 8, 9, and 10 shows that the structural displacements are concentrated at the ground floor with severe damages to the ground floor walls and the slab frame. We observed upward-down displacements of the ground floor slab frame and this shows that the seismic waves (vertical components) were not adequately absorbed by the upper floors. The second floor of the building lying immediately above the damaged floor was excessively reinforced. In other words, the stiffness of the second floor is too high compared to the first floor. Consequently, the seismic waves were reflected back causing high level of impacts and resulted to a decrease in the stiffness of the lower floor slabs and the load bearing columns. This in turn resulted to severe damages of the walls and the slab frame with little or no effects on the upper floors.

DISPLACEMENTS

Table 1. Tabular representation of the observed displacements

#	Output Case	Case Type	Step Type	U1	U2	U3	R1	R2	R3
1	Time history	LinRespSpec	Max	21.1535	2.4212	1.4291	0.4261	0.3394	1.4772
2	Spectrum 2004	LinRespSpec	Max	0.0730	0.2258	0.0005	0.0001	0.0001	0.0094

In general, the displacements observed in modal-time history analysis are higher than modal-spectrum Eurocode 2004 based analysis.

3.2 Analysis of the Model after Strengthening

The results of these analyses are presented here in form of pictures.

DEFORMED SHAPE

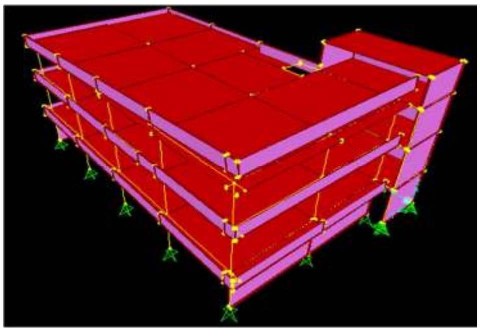

Figure 11. Deformed shape of the model

VULNERABLE AREAS

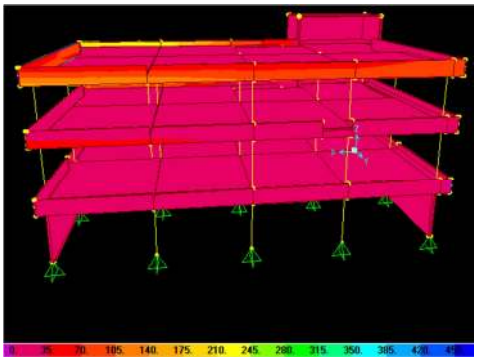

Figure 12. Stress SMAX Distribution

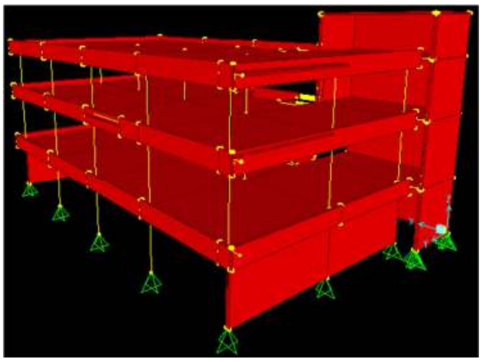

Figure 13. Torsional Force Distribution

The results from Figure 11, 12, and 13 shows that the deformed shape of the model are different from the one observed earlier before strengthening. The stiffness of the basement has been increased and the behaviour of the structure is better than the one observed earlier. After strengthening, the ground floor including the basement was more stable than the upper floors and least displacements were observed at the ground floor.

DISPLACEMENTS

Table 2. Tabular representation of the observed displacements

#	Output Case	Case Type	Step Type	U1	U2	U3	R1	R2	R3
1	Time history	LinRespSpec	Max	1.1533	1.4212	0.1281	0.1281	0.0552	0.0812
2	Spectrum 2004	LinRespSpec	Max	0.0030	0.0255	0.0001	0.0001	0.0001	0.0012

The displacements obtained from Modal-Response Spectrum Analysis are also higher than that of Modal Response Analysis. When compared with the analysis of the structure before strengthening, the displacements obtained after strengthening are generally lower. This is another indication of the improvement in the performance of the structure.

4. Conclusion

The ability of a structure to resist seismic actions and loads depends on the stiffness of the structure, and it has been proved that the higher the stiffness of a structure, the better the ability of a structure to resist seismic loads. However, the distribution of structural stiffness within a building still constitutes major challenges in the field of structural earthquake engineering.

The behaviour of the collapsed building before strengthening was unsatisfactory and the failure of the structure can be attributed to its poor design. The distribution of the stiffness in the structure was not well taken care of and this is the basis of the observed damages that the building sustained when the earthquake occurred. The reduction in the stiffness and resulting friction of the ground floor slabs, and the load bearing columns were the main causes of the building collapse.

The lesson here for developing countries is to develop appropriate mechanism(s) for post-collapse structural analysis and remedy of buildings.

Acknowledgements

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