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Strengthening of existing security buildings against vehicle bomb using fluid viscous dampers, in Egypt

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This paper presents nonlinear numerical simulation of air blast loading with an over pressure level (500 kg TNT) with a different standoff distance of 10, 20, and 50 m to evaluate the effectiveness of Fluid Viscous Dampers (FVD) as new strengthening techniques to reduce blast loading responses on the existing reinforcement concrete buildings. Taking into consideration, most of the security buildings in Middle East, especially in Egypt, during the last three decades, had suffered many blast attacks. This paper presents nonlinear numerical modeling to study the effect and performance comparisons of a conventional structural building frame system with and without FVD. Simulation results indicate that FVD provide a cost-effective way to greatly improve the performance of structural building frames under blast loading.

Key words: Air blast loading, security building, strengthening of exciting building, fluid dampers, vehicle bomb.

INTRODUCTION

In buildings lifetime, building structures could be exposed to extreme natural phenomena (earthquakes, tornados, fire, natural floods) and anthropogenic phenomena (blast or impact). Structures are not usually designed for extreme loadings and when such events occur, it can lead to catastrophic failure. Recently, terrorist attacks targeted security and important buildings led to structural collapse, with important human lives and buildings damages. The term "progressive collapse" refers to the development of an initial local failure (TM 5-1300, 1990; Jankowiak and Tomasz, 2005), which could lead to local or total crush. The main characteristic of progressive collapse is the significant disproportion between initial phase and the final state. Vehicle bomb is one of the famous and repeated ways to attack security buildings that has been a feature of campaigns waged by terrorist organizations throughout the world.

A bomb explosion inside or directly beside a building can cause catastrophic damage to the building's external and internal structural frames, collapsing of walls, cladding, facades, and shutting down of critical life-safety systems. There are many rezones beyond the casualties and injuries among a building's occupants such as direct blast-effects and structural collapse.

The progressive collapse became an interesting topic for building designers and researchers after the partial collapse of the Ronan Point block in London 1964 and the importance of that subject has highly increased with recent terrorist activities throughout the world. Extreme events as blast and impact, considered improbable in the past, were moved to credible events, having a finite probability of occurrence (Lee et al., 1973; Zhongqi et al.,

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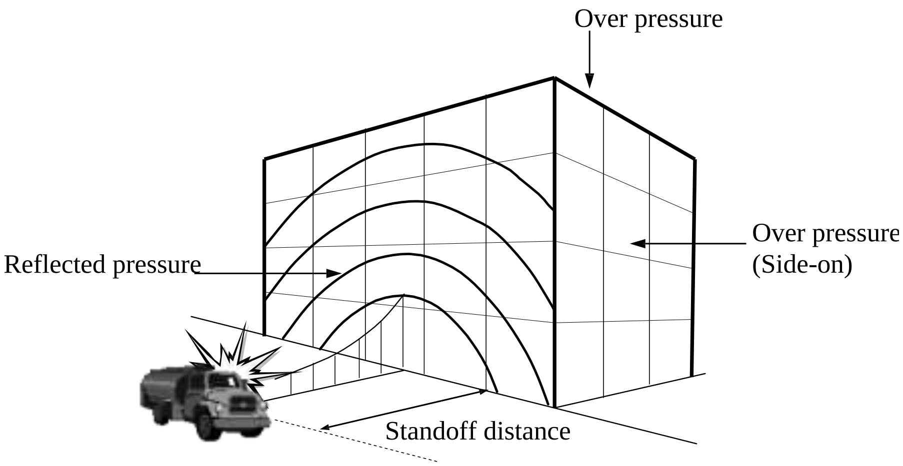

Figure 1. Blast loads effects on building.

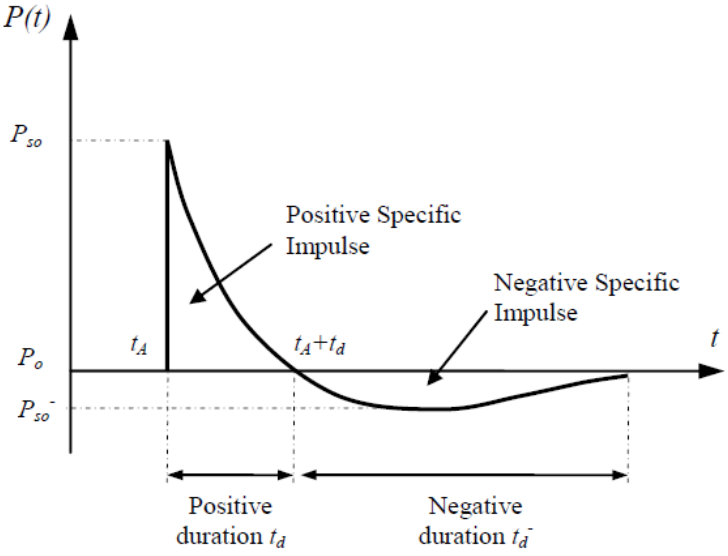

Figure 2. Time history function of blast wave pressure on building.

2004).

Figure 1 presents conventional truck bomb with the blast effect pressure on buildings. The major effective parameters can be defined by charge weight of TNT and standoff distance between the blast source and building. Blast wave instantaneously increases to a value of pressure above the ambient atmospheric pressure. Side-on over pressure decays as the shock wave extends outward from explosion source. After a short time, the pressure behind the front side of the building may drop below the ambient pressure. Suction wave is also accompanied by high suction winds that carry the debris for long distance away from the explosion source (Longinow and Mniszewski, 1996).

Air blast wave's characteristics are found to be affected by physical properties of the explosion source. Figure 2 shows a typical blast pressure profile. At the arrival time t_A, following the explosion, pressure at that position suddenly increases to peak value of over pressure, P_{So}, over the ambient pressure P_o. The pressure then decays to ambient level at time t_d, then decays further to an under pressure P^-_{so} (creating a partial vacuum) before eventually returning to ambient conditions at time $t_d+t^-_d$. The quantity of P_{So} is referred to the peak value of overpressure (side-on) (TM 5-1300, 1990).

All blast parameters are primarily dependent on the amount of energy released by a detonation in the form of a blast wave and the distance from the explosion.

Figure 3. General view of Directorate of Security in Daqahlia Government.

A universal normalized description of the blast effects can be given by scaling distance relative to $(E/P_o)^{1/3}$ and scaling pressure relative to P_o, where E is the energy release (kJ) and P_o the ambient pressure. For convenience, however, it is general practice to express the basic explosive input or charge weight was an equivalent mass of TNT. Results are then given as a function of the dimensional distance parameter (scaled distance) $Z = R/W^{1/3}$, where R is the actual effective distance from the explosion, W is generally expressed in kilograms. Scaling laws provide parametric correlations between a particular explosion and a standard charge of the same substance (TM 5-855-1, 1986).

SECURITY BUILDING IN EGYPT: STUDY CASE

Until 1997, security buildings were developed by the Ministry of Interior in all Provinces in Egypt. After 2000, typical projects have been prepared by the General Authority for Security Buildings (GASB) with the increase in terrorist attacks rates resorted (GASB) of the Egyptian Interior Ministry of the Interior. Provincial directorates have the responsibility for construction supervision of these security buildings. Although, these typical projects display minor differences from one province to another, they are architecturally similar.

GASB has divided security buildings into seven models. This classification was based on two main items. The first is the capacity and function of building; while the second is the security level that depends on the construction site.

The general and common characteristics of mid-security level buildings designed by GASB are as follows:

(1) The load-bearing system of these buildings is composed of a reinforced concrete column and beam system with or without shear walls.
(2) Interior Ministry Buildings are designed and constructed in accordance with ECP- 201 (2007) for loading and ECP-203 (2008) for reinforcement concrete design.
(3) Spaces inside the buildings are created through non-load bearing brick walls.

In this research, the middle of Delta Region in Egypt has been chosen as an objective of research, where all security buildings are classified as mid-security level of buildings. In addition, most of these buildings were built based on old criteria put into consideration, that is, the security requirements in terms of the structural design of buildings. The case study is a directorate of security that consists of a basement, ground floor, and four typical floors, located in Daqahlia Governor (Middle of Delta, located in North of Egypt).

Figure 3 shows photos of Directorate of Security (case study), which recently suffered a car bombing. This case study was chosen to represent a wide range of buildings located in middle of Delta region. This will enable the preparation of 3D finite element models for comparison with and without Fluid Viscous Dampers (FVD) strengthening techniques due to the different level of blast loads (500 kg TNT) with a different distance a building (10, 20, and 50 m). The statistical system of this public security building is normal skeleton reinforcement concrete building beam and columns system without a shear wall where this building was constructed 1975. Figure 4 presents general architectural and structural layout of typical floors.

Concrete material modelling properties

Under dynamic load conditions, the mechanical properties of concrete have different significant changes compared to concrete under static loads. Figure 5 presents stress strain curve of concrete under static and dynamic loads, respectively. The stresses that are sustained for a certain period of time under dynamic conditions may gain values that are remarkably higher than the static compressive strength. Strength magnification factors as high as 4 in compression and up to 6 in tension for strain rates in the range of 10^2 to 10^5 s^{-1} have been reported (Grote et al., 2001).

The concrete’s natural characteristics are presented in Table 1, used in the finite element modeling case study of security building which is fully constructed of reinforcement concrete as shown in Figure 4 as frame skeleton reinforcement concrete structures.

Finite element modelling

In the finite element modeling, the original ordinary

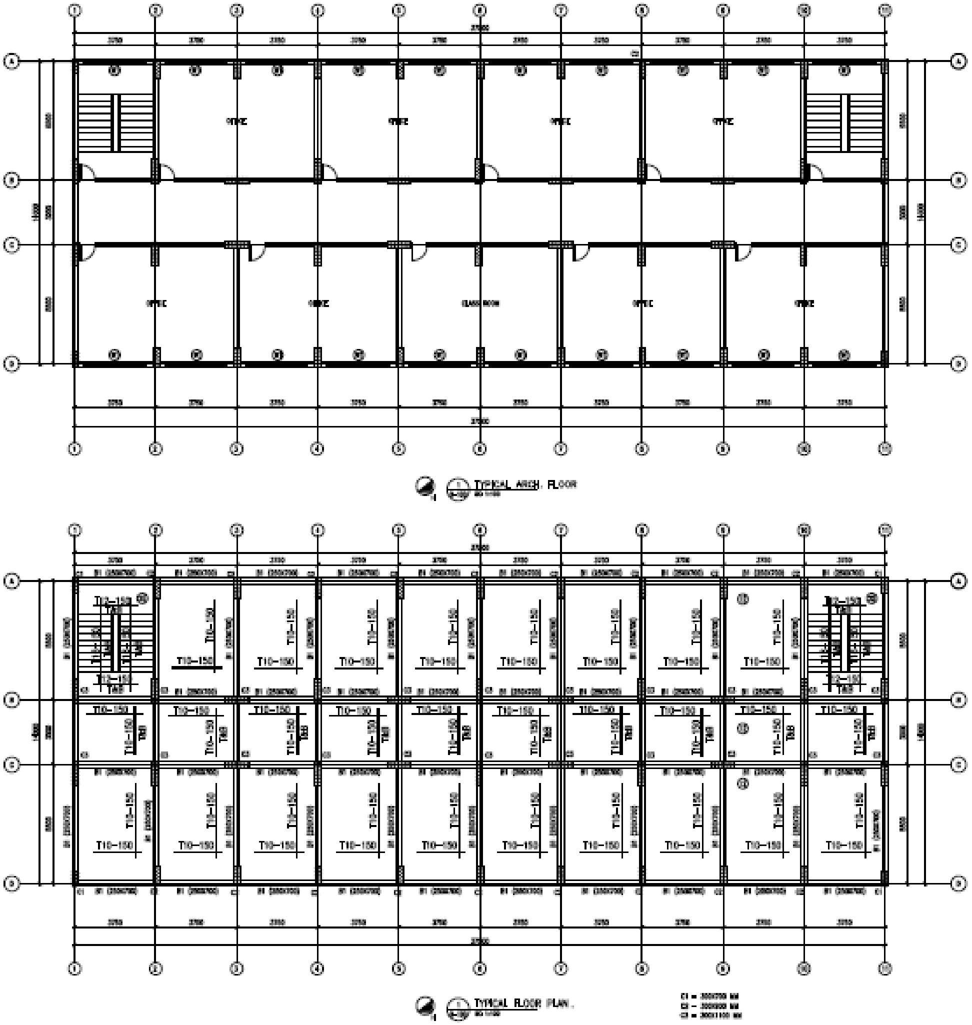

Figure 4. Architectural and Structural plan of case study, (Directorate of Security of Daqahlia).

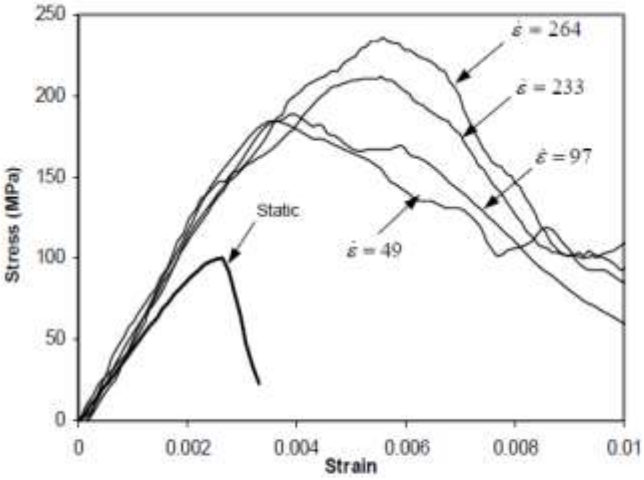

Figure 5. Stress-strain curves of concrete at different strain-rates (Ngo et al., 2004a).

Table 1. Material properties of the RC structure (Jankowiak and Tomasz, 2005).

The parameters of CDP model	Value
Young's modulus E (GPa)	19.7
Poisson's ratio ν	0.19
Concrete strength (Mpa) (Cube)	30
β	38°
Flow / potential eccentricity (ε)	1
σ_{b0} / σ_{c0}	1.12
K_c	0.666

Table 2. Modeling of TNT explosive parameters [JWL parameters]

Parameter	Value
Detonation Wave Speed, C_d	6930 m/s
A	373.8 GPa
B	3.747 GPa
R_1	4.15
R_2	0.9
ω	0.35
The Density of The Explosive ρ_0	1630 kg/m^3
Initial Specific Energy E_{m0}	3.63 Joule/kg

building of the case study was modeled in accordance with the nonlinear explicit code LS-DYNA (2002), which takes into consideration material nonlinearity and geometric nonlinearity (Stewart and Morrill, 2015). The super structure was simulated as reinforcement skeleton structure system beams and columns as frame element, for slabs was assumed as shell elements (solid slabs) with diaphragm in the orthogonal direction of horizontal expected motion. The soil structural interaction was neglected and all columns in foundation level have fixed boundary condition. The explosive charge (TNT) is modeled using the Jones Wiilkens-Lee (JWL) equation of state. It simulates the pressure generated by explosion of the detonation product (Lee et al., 1973). The parameters of the TNT charge with the properties presented in Zhongqi et al. (2004) are listed in Table 2.

In this study, the security building was chosen as case study to be exposed of the explosive pressure force of 500 kg TNT by offering two proposals; in the first proposal, the security building, which is the original state of the building, while the second proposal will address the same building in the same conditions and assumptions made using FVD as a way of strengthening the building against the impact generated by the forces of the explosion.

Figure 6 presents general view of the Taylor FVD, which was 60 and 20 pieces, erected from ground up to roof level in X Shape for longitudinal and transversal direction, respectively. Table 3 is the general information Taylor FVD (Miyamoto and Taylor, 2016).

Due to the FVD, the overall structural additional damping ration was increased in longitudinal and transversal direction of exciting building by 2.21 and 2.36%, respectively. Some cross brace configurations were used due to limited space and FVD were used in locations where there was no space for a brace but additional stiffness was needed.

$$\Phi = K_{\varepsilon\phi\phi}\ .\ \upsilon + Xu^{\alpha} \qquad (1)$$

where K_{eff}= equivalent stiffness of the liquid flexible unit; C = damping coefficient; u = the displacement of the piston rod; $\dot{u}$ = the motion velocity of the piston rod; and α = velocity exponent.

INTERPRETATION OF NUMERICAL ANALYSIS RESULTS

Figures 7 and 8 present over stress at the case study columns if the corner column and edge column in edge column in transversal direction were completely burst, respectively due to blast loading with explosion loading rate 500 TNT at different standoff distance of 50, 20, and 10 m for the structure.

After destroying the column, the efforts that were initially

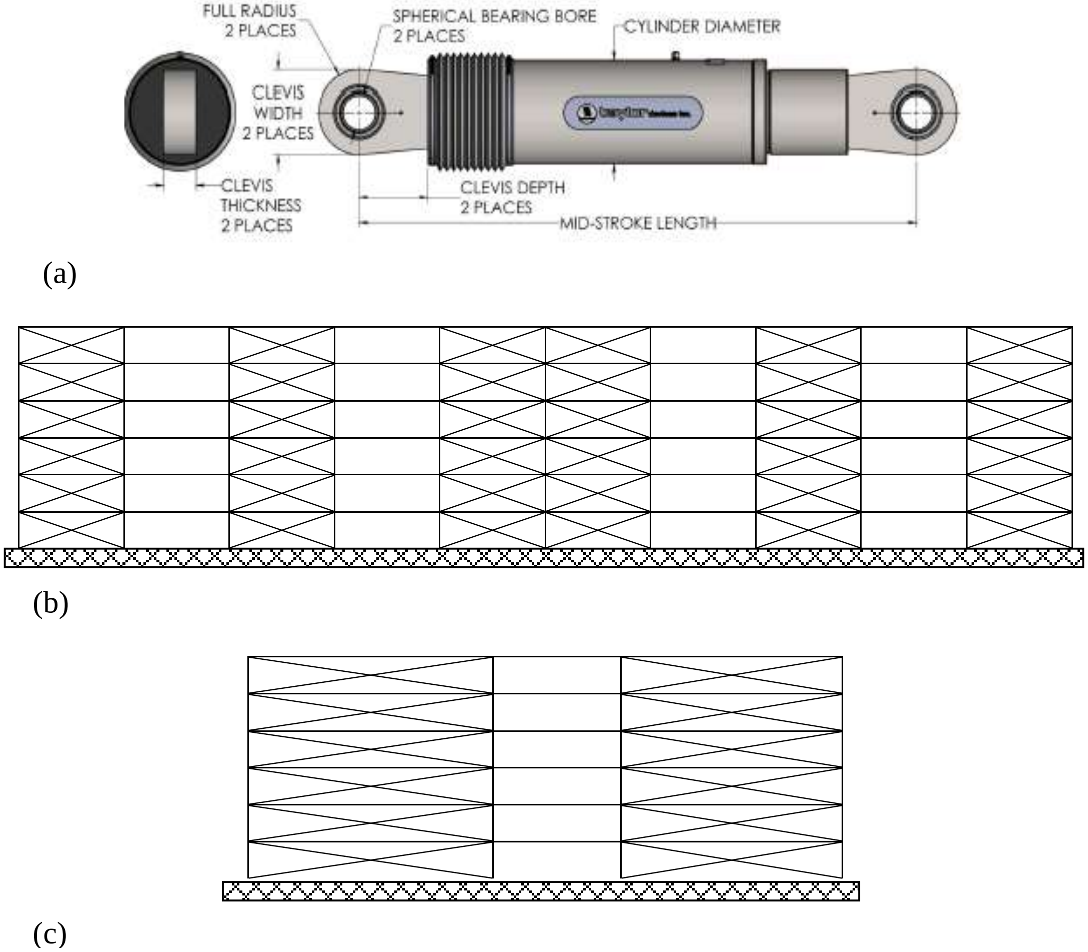

Figure 6. (a) Cross section of Taylor Fluid Viscous Damper, FVD; (b and c) Arrangement of Taylor FVD in Longitudinal and Transversal direction of case study, respectively.

Table 3. General information on damper parameter.

No.	types	Stiffness (kN/m)	Vel. Exp.*α*	*C* (kN.(s/m) α)	*F* (kN)	*D* (mm)	Qua.
1	FVD	700	0.3	3000	1000	±100	80

undertaken by this column are redistributed to the adjacent beams through the slab and then to the next columns. The bending moments in the beams connected to the considered column, having an initial negative value, become positive after the removal event. Along with the slab, the beams redistribute a part of the extra loads to the adjacent columns.

Figure 9 presents the blasting loads effect of loading rate 500 kg TNT at standoff 50 m distance from the structural building. Figure 9a, b, and c presents the axial forces reaction redistribution due to explosion corner, transversal, and longitudinal, respectively. In Figure 9a, b, and c, the axial force before the event of explosion and the axial force of columns after explosion present the extra load value and percentages for the others two columns. The same figures show the values of axial loads present with FVD, which was erected as presented in Figure 6b and c.

The axial force of adjacent columns in longitudinal and transversal directions is increasing by 16.8 and 25.9%, respectively as shown in Figure 8a. In case of erecting FVD as facade bracing, the increase of axial force for the same columns will be 6.3 and 9.6% with decrease percentages of 10 to 15%, due to the application of FVD

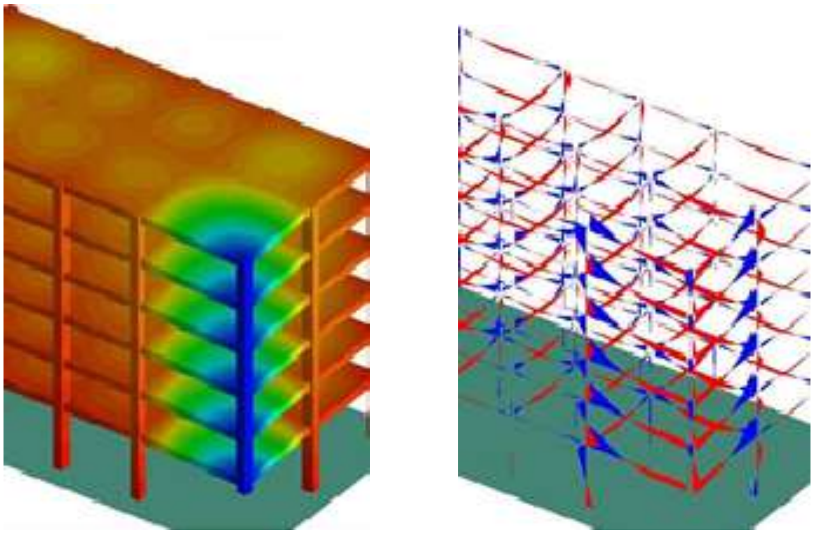

Figure 7. Case of corner column removal.

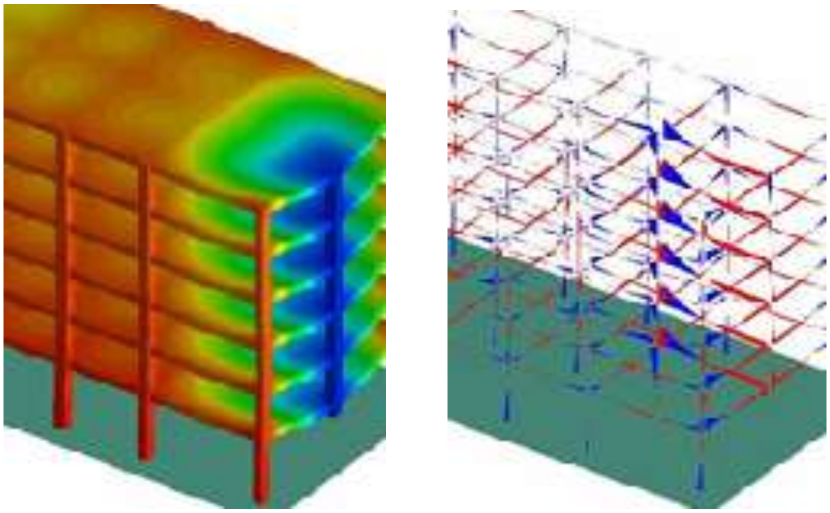

Figure 8. Middle column of short side of structure removal case.

in the redistribution of exploded corner column, as well as, absorption of force of air blasting.

Figures 10 and 11 present the blasting of loading rate of 500 kg TNT with 20 and 10 m standoff distances, respectively. For the cases, Figure 8a, b, and c present the axial force increasing percentages of the remaining columns in case of explosion corner, adjacent column of longitudinal, and transversal columns, respectively; for exciting skeleton security building (case study) as per the conventional system, without and with FVD for strengthening the building.

Axial forces percentage of conventional system is bigger than 25% with standoff distance 10 m compared to 20 m standoff distance as shown in Figures 10 and 11, respectively.

The increasing rate is not linear, where blast loading effects on structural members may produce both local and global responses associated with different failure modes. The type of structural response depends mainly on the loading rate, the orientation of the target with respect to the direction of the blast wave propagation and boundary conditions. The general failure modes associated with blast loading can be flexure, direct shear or punching shear. Local responses are characterized by localized explosion of columns, and generally, result from the close-in effects of explosions, while global

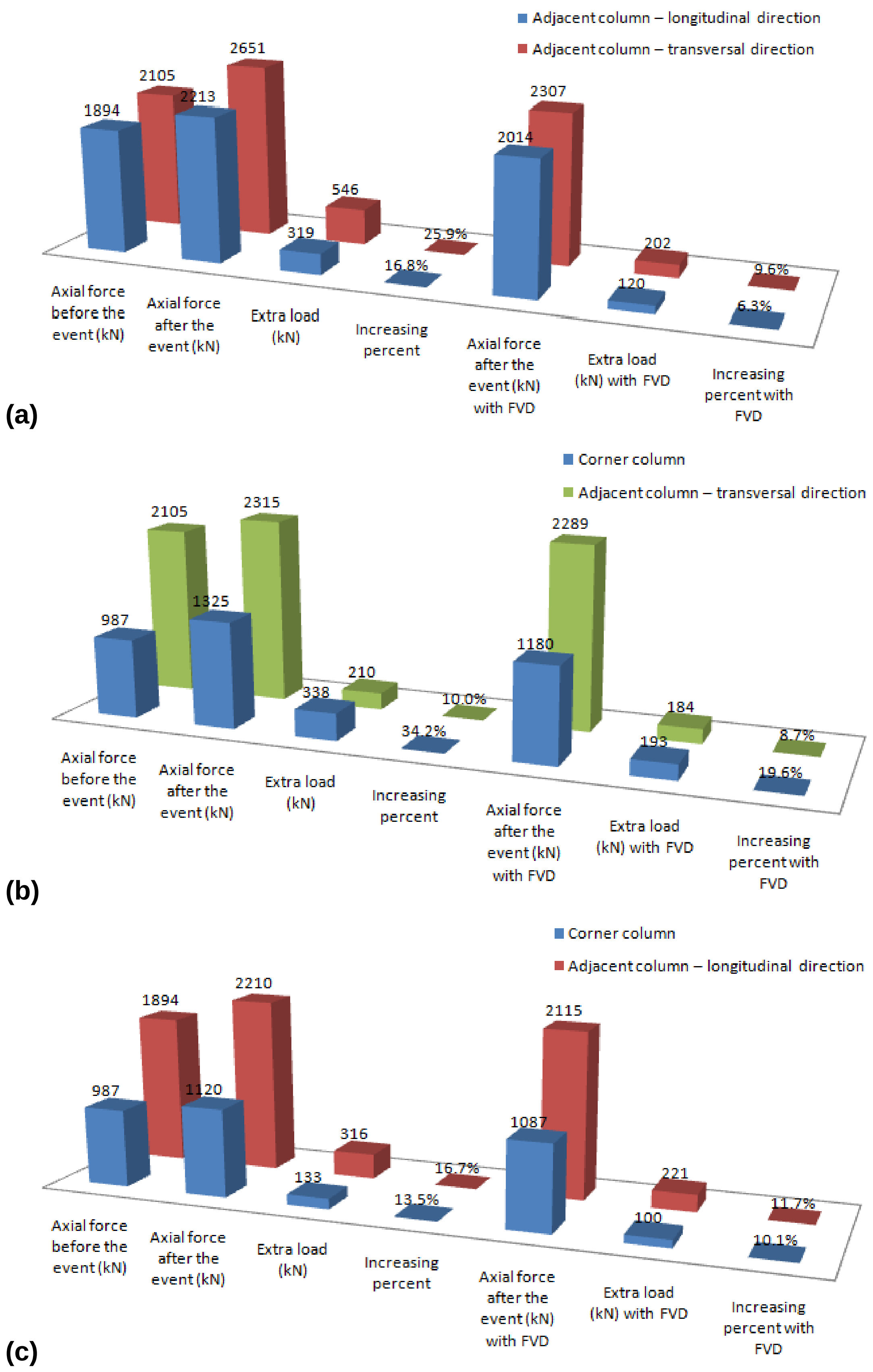

Figure 9. Redistribution value of columns axial forces of corner, adjacent longitudinal and transversal directions, respectively (500 kg TNT at standoff distance 50 m).

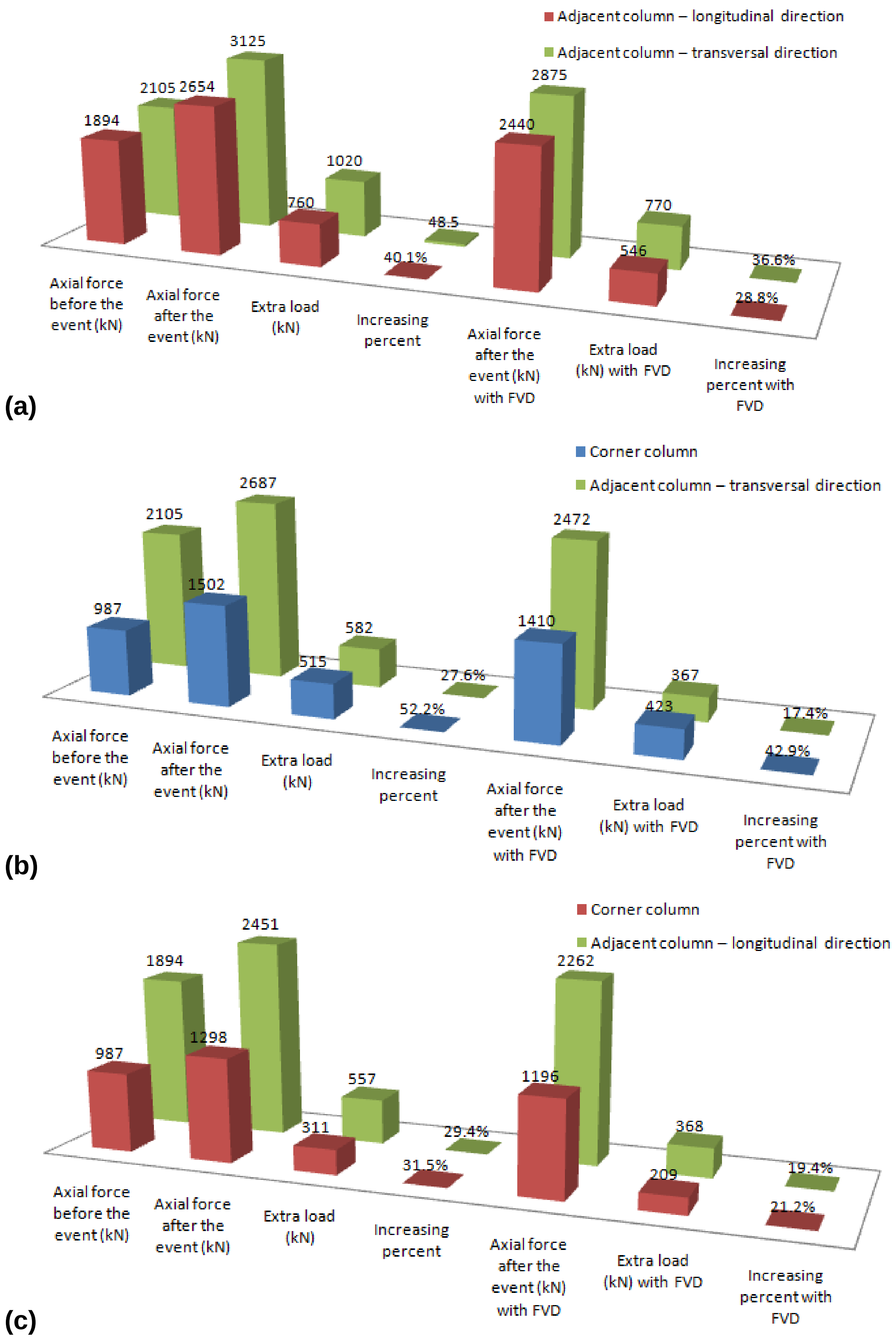

Figure 10. Redistribution value of columns axial forces of corner, adjacent longitudinal and transversal directions, respectively (500 kg TNT at standoff distance 20 m).

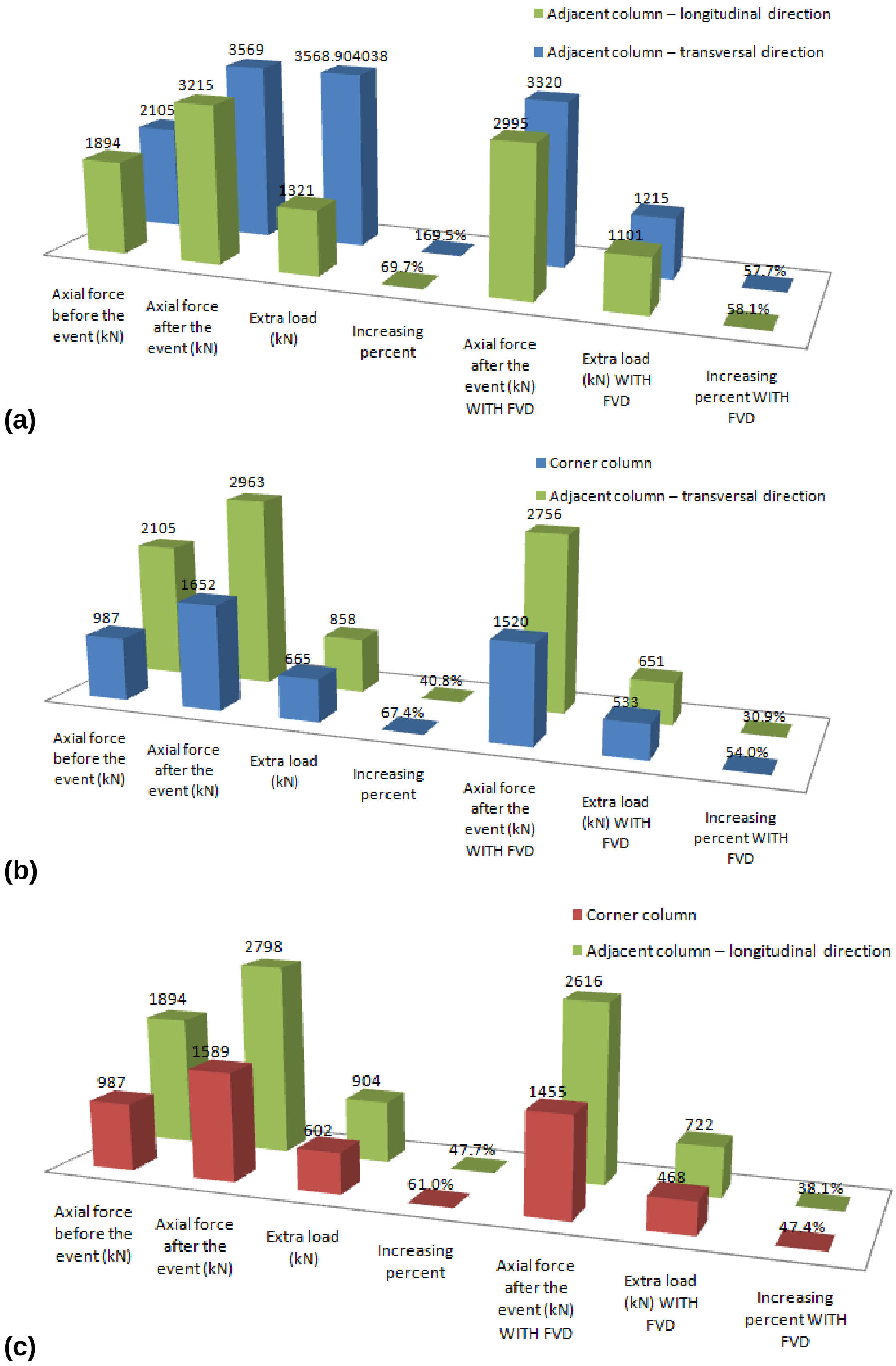

Figure 11. Redistribution value of columns axial forces of corner, adjacent longitudinal and transversal directions, respectively (500 kg TNT at standoff distance 10 m).

responses are typically manifested as flexural failure.

The close-in effect of explosion may cause a localized shear or a flexural failure at the closest structural elements. This depends mainly on the distance between the source of the explosion and the target, and the relative strength/ductility of the structural elements. The localized shear failure takes place in the form of a localized punching and an explosion, which produces low and high-speed fragments.

Figures 9, 10, and 11 present the effect of the Fluid Viscous Damper upon erecting it as a façade bracing in the longitudinal and transversal directions of exciting security building; the air blasting loads effects at all different standoff distance 50, 20, and 10 m will be decreased where FVD is being worked as an energy dissipation devices. Also, it succeeded to be working into the redistribution of straining action on the other columns through horizontal elements like slabs and beams, which efficiency improve the overall structural performance under blasting loads as compared to conventional systems.

CONCLUSION

This paper numerically investigated the behavior of conventional skeleton structural system of the security buildings in Egypt as case study subjected to a high level of air blast loading (500 kg TNT), with different standoff distances 50, 20, and 10 m as compared to the same case study with FVD as strengthening tools.

(1) For high risks facilities such as security buildings in Egypt, design consideration against extreme events (bomb blast and vehicle bombs) is very important to taken into consideration. Egyptian code of provisions on progressive collapse prevention should be included in the current Egyptian building regulations and design standards where it was missing in Egyptian codes.

(2) Fluid viscous damper as supplements devices should be succeeded to reduce the overall axial force on the adjacent columns of destroyed columns by average percentages of 10 to 17%, for the different standoff distances of blasting loads. FVD is considered effective strengthening technique. FVD worked with the geometrical configuration of the model and the reinforcement position allowed for effort redistribution, so that the collapse can be avoided, which proved to be an effective technique especially for exciting security buildings.

Conflict of interest

The author has not declared any conflict of interests.

REFERENCES

ECP-201 Permanent Committee (2008). ECP-201:1993, ECP-201:2003, and ECP-201:2008 - Egyptian Code for calculating loads and forces in structural work and masonry, HBRC, Giza.

ECP-203 Permanent Committee (2007). ECP-203:2007- Egyptian Code for design and construction of concrete structures, HBRC, Giza.

Grote D, Park S, Zhou M (2001). Dynamic behavior of concrete at high strain rates and pressures. J. Impact Eng. 25:869-886. Pergamon Press, New York.

Jankowiak T, Tomasz L (2005). Identification of parameters of concrete damage plasticity constitutive model. Foundations of Civil and Environmental Engineering 6(1):53-69.

Lee E, Finger M, Collins WJWL (1973). Equations of state coefficient for high explosives, in Lawrence Livermore Laboratory, Livermore, Calif, UCID-16189.

Longinow A, Mniszewski KR (1996). Protecting buildings against vehicle bomb attacks", Practice Periodical on Structural Design and Construction, ASCE, New York, pp. 51-54.

LS-DYNA Version 960 (2002). Livermore Software Technology Corporation.

Miyamoto KH, Taylor DP (2016). Structural control of dynamic blast loading using fluid viscous dampers, Technical report.

Stewart LK, Morrill KB (2015). Residual capacity prediction of blast-loaded steel columns using physics-based fast running models. Int. J. Safety Security Eng. 5(4):289-303.

Taylor Fluid Viscous Dampers FVD, The world leader in innovative shock and vibration control (http://taylordevices.com/).

TM 5-1300 (1990). The Design of Structures to Resist the Effects of Accidental Explosions, Technical Manual, US Department of the Army, Navy, and Air Force, Washington DC.

TM 5-855-1 (1986). Fundamentals of Protective Design for Conventional Weapons, U.S. Department of the Army, Washington DC.

Zhongqi W, Yong L, Hong H (2004). Numerical Investigation of Effects of Water Saturation on Blast Wave Propagation in Soil Mass. J. Eng. Mech. 130(5):551-561.