Analysis and Assessment of RC Structures Exposed to Explosions

Course No: S01-012
Credit: 1 PDH

Ibrahim M. Metwally, Ph.D., P.E.

CED engineering.com
PDH FOR THE PROFESSIONAL

Continuing Education and Development, Inc.

P: (877) 322-5800
info@cedengineering.com

Table Contents

List of Figures

Protective Design Strategy of Blast-Resistant Structures

Reduce Blast Demands, HOW?

The Main Strategy for blast-resistance structures design is to reduce blast demands, which means to reduce deformation in structural and non-structural building components.

This is achieved through:

1. **Increasing Standoff Distance:** Providing sufficient protection by increasing protected standoff distances against external attacks.

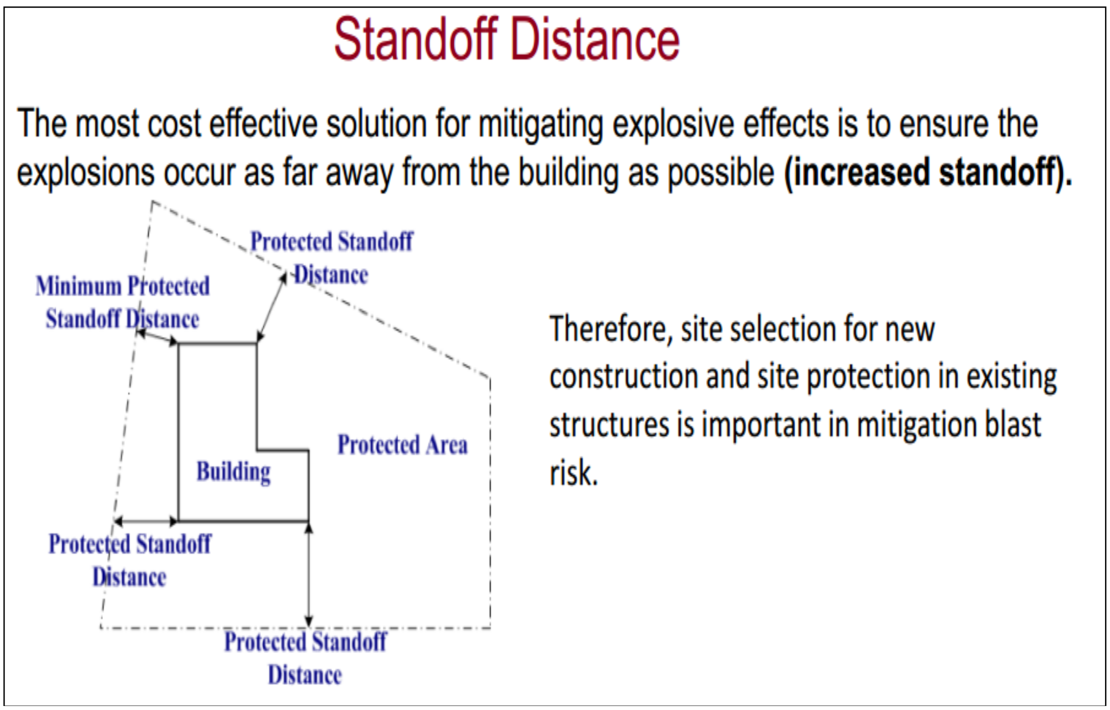


Figure 1. Standoff Distance

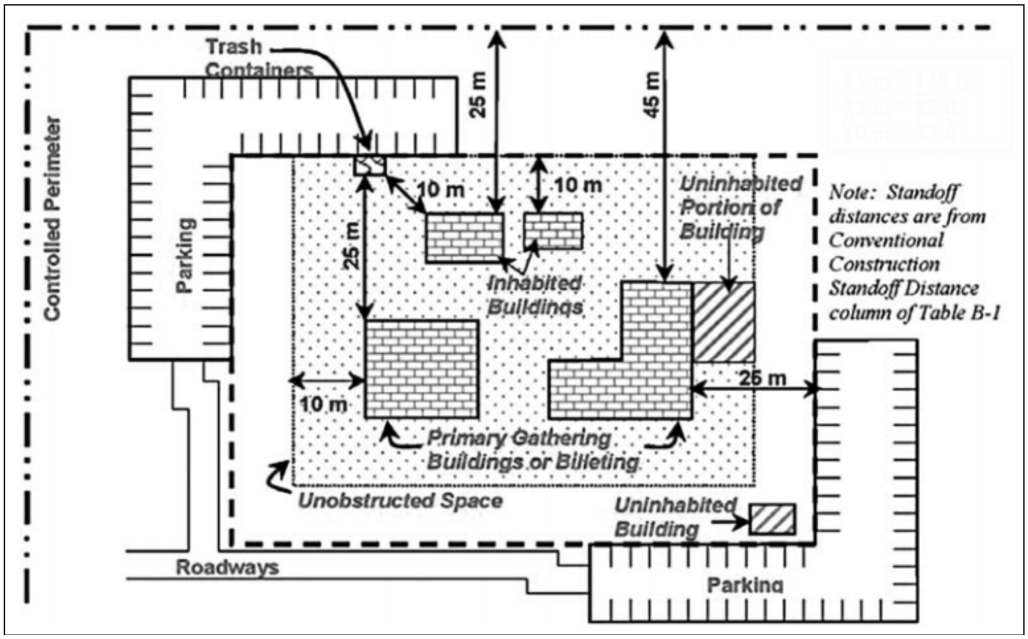


Figure 2. Minimum Standoffs for Buildings of Conventional Construction with a Controlled Perimeter according to DoD 2007a[1] specifications

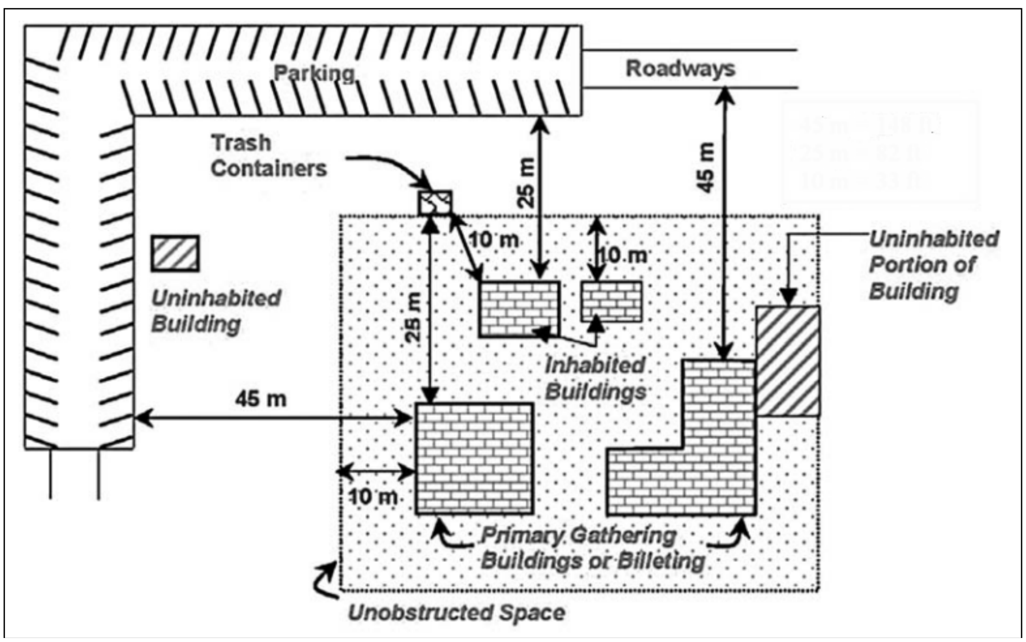


Figure 3. Minimum Standoffs for Buildings of Conventional Construction Without a Controlled Perimeter according to DoD 2007a[1] specifications

2. Use of Protective Barrier Walls

Many types of barriers are designed to resist the impact of a vehicle bomb. Among them are *massive concrete barriers* (Kontek 2008[2]), *concrete enclosed with steel plates* (Crawford and Lan 2006[3]), and *soil filled corrugated metal* (Crawford and Lan 2006[3]).

Few representative barriers are shown in the following figure. Each barrier is designed to absorb the large amounts of energy from an impact or blast with minimal effect on the facilities it is protecting.

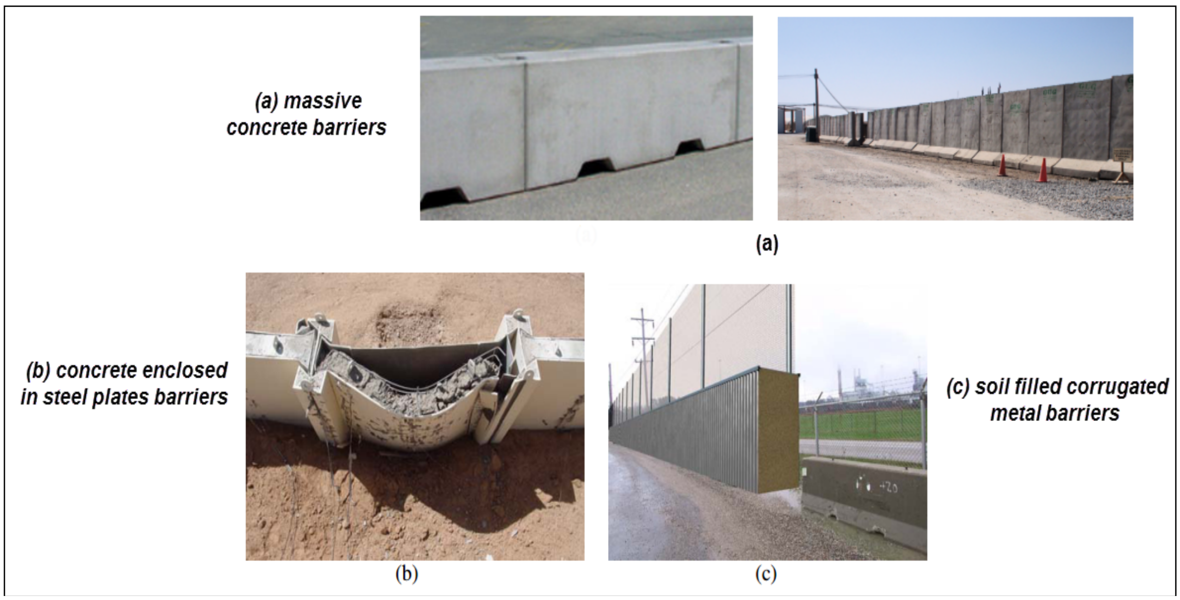


Figure 4. Use of Protective Barriers Walls

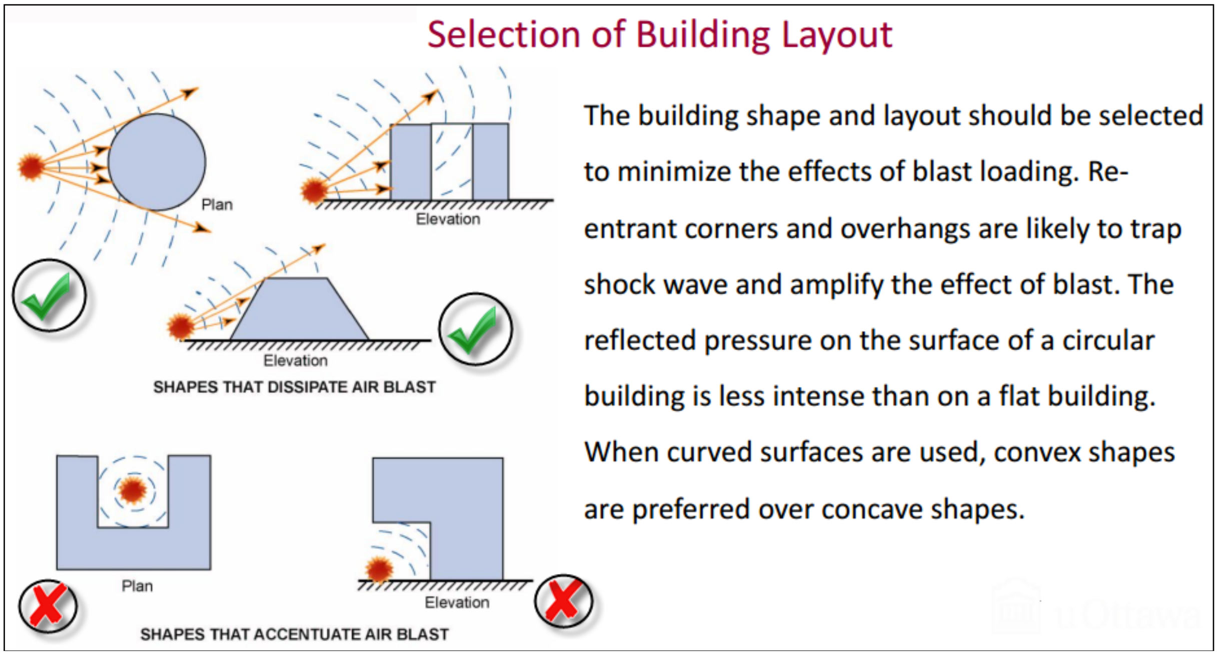


Figure 5. Proper Selection of Building Layout

Desirable Structural Forms

Figure 6. Arches

Figure 7. Domes

Figure 8. Single Story Buildings

Undesirable Structural Forms

Figure 9. Complex Shapes

Figure 10. Projecting Roofs or Floors

Figure 11. U-Shaped Building

Figure 12. Multistory Buildings

FEMA 427[4] - Recommendations:

- ❑ Use simple geometries without sharp re-entrant corners.
- ❑ Place the building on the site as far from the perimeter as practical.

Proper Selection of Structural System According to FEMA 427[4] Guidelines

Frame System

- ❑ In frame structures, column spacing should be limited. Large column spacing decreases the likelihood that the structure will be able to redistribute load in the event of column failure.
- ❑ In frame structures, the exterior columns should be designed to resist the direct effects of the specified blast.
- ❑ The frame structures system should be designed to resist the likely progressive collapse. In case of occurrence of any localized failure.
- ❑ It should not use **TRANSFER GIRDERS**. Loss of a transfer girder or one of its supports can destabilize a significant area of the building. If transfer girders are required, it must be to add extra transfer systems, as shown in the following figures.

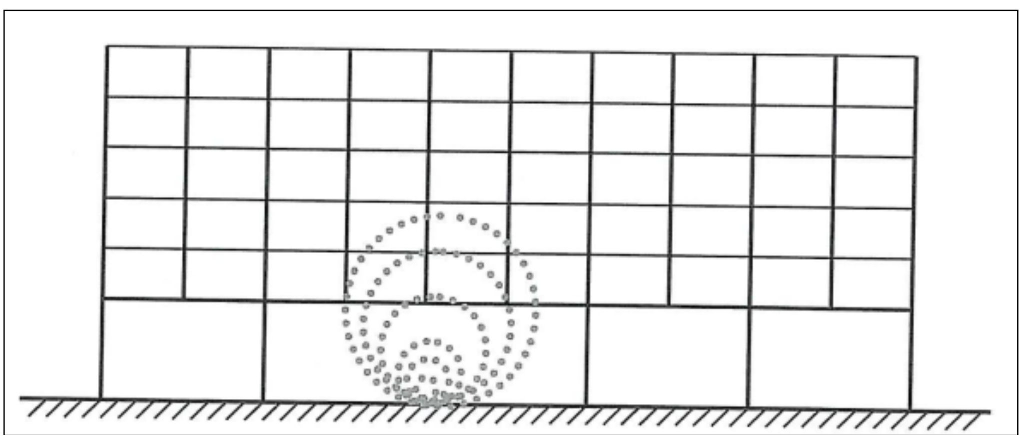


Figure 13. Detonation and Destruction of One Main Column

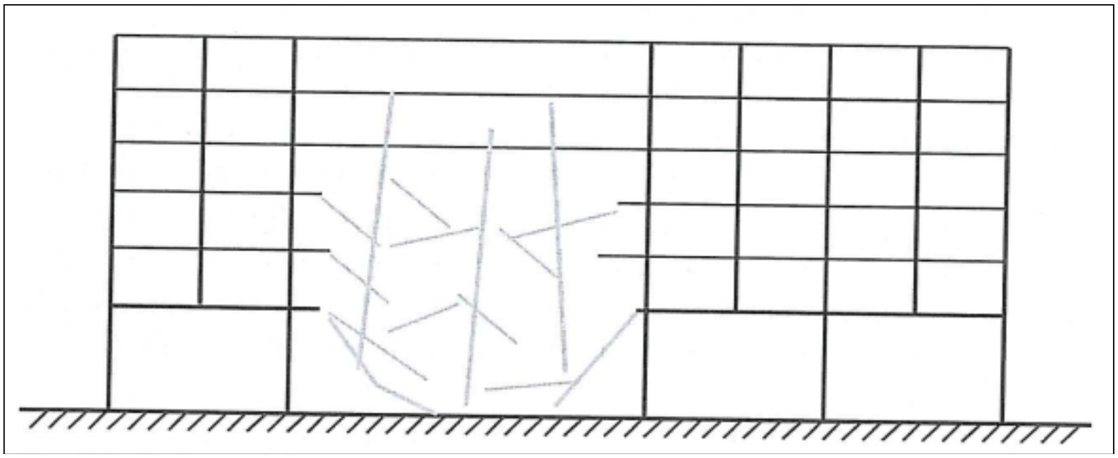


Figure 14. Failure of the transfer girder and secondary columns

Bearing-Wall Systems

- In bearing-wall systems that rely primarily on interior cross-walls, interior longitudinal walls should be spaced to enhance stability, and control the lateral progression of damage.
- In bearing-wall systems that rely on exterior walls, perpendicular walls should be provided at a regular spacing to control the amount of wall that is likely to be affected.

Roof System

- The primary loading on the roof is the downward air-blast pressure.
- The preferred system is cast-in place reinforced concrete with beams in two directions.
- If this system is used, beams should have continuous top and bottom reinforcement with tension lap splices.
- Stirrups to develop the bending capacity of the beams closely spaced along the entire span are recommended.
- Use two-way floor and roof systems.

Proper Selection of Structural Material

Which Building Materials Are Preferred?

- Cast-in-place reinforced concrete is the structural system preferred for blast-resistant construction. This is the material and structural type used for military bunkers. The military has performed extensive research and testing of its performance. Concrete has significant mass, which improves response to explosions.
- Generally, simple geometries and minimal ornamentation (which may become flying debris during an explosion) are recommended. If ornamentation is used, it is preferable to use ***lightweight materials such as timber or plastic***, which are less likely than brick, stone, or metal to become lethal projectiles in the event of an explosion.
- Ultra High Performance Concrete (UHPC)

  UHPC is known for its superior mechanical properties; compressive strength can reach up to 200 MPa, and tensile strength up to 40 MPa. Also, the crack propagation can be well controlled due to inclusion of steel fibers in its cement matrix, leading to a higher ductility and energy absorbing capacity so as to make it an ideal material for structural members that are exposed to the constant threat of blast attacks. Previous experimental work conducted by Mao et al., Wu et al.,[5] Barnett et al.,[6], Ibrahim Metwally[7], Schleyer et al.[8], and Melançon[9] confirmed the superior blast resistance of UHPC structures under high loading rate conditions such as explosion and impact compared to traditional normal and high strength concrete.

Increase the Capacity of the Ground Floor Columns

Concrete-filled steel columns have high ductility and very good blast resistance, Peyman, et al.[10], Ibrahim Metwally[7], and Zhang, et al.[11]

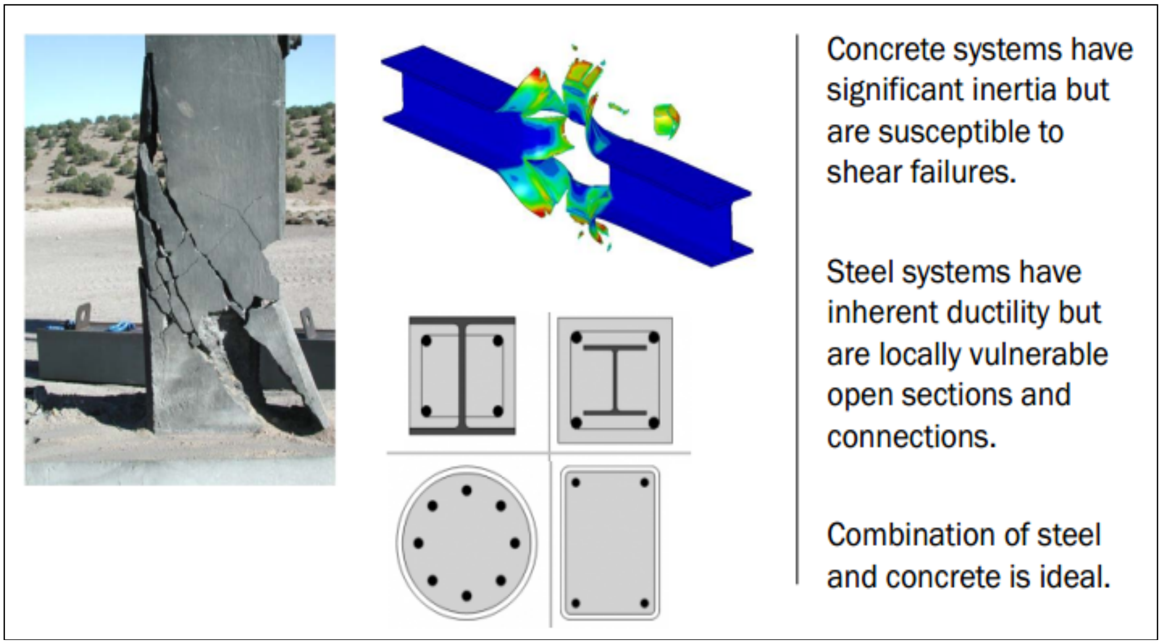


Figure 15. Ground Floor Columns

Ductile Structural Elements

Ductile detailing of reinforcements:

- Blast-resistant design philosophy allows structural elements to undergo large inelastic (plastic) deformations under blast loading.
- A ductile structure that undergoes large deformations without failure can absorb much more energy than a brittle structure of the same strength.
- Tensile reinforcement between 0.5 and 2% of the cross-sectional area of the concrete element will usually insure ductile behavior while providing the required strength.
- Compression steel in flexural members serves two purposes. After a structural member is deflected by blast loads, it attempts to spring back or rebound. *Dynamic rebound causes load reversal and, under certain conditions, can result in catastrophic failure.*

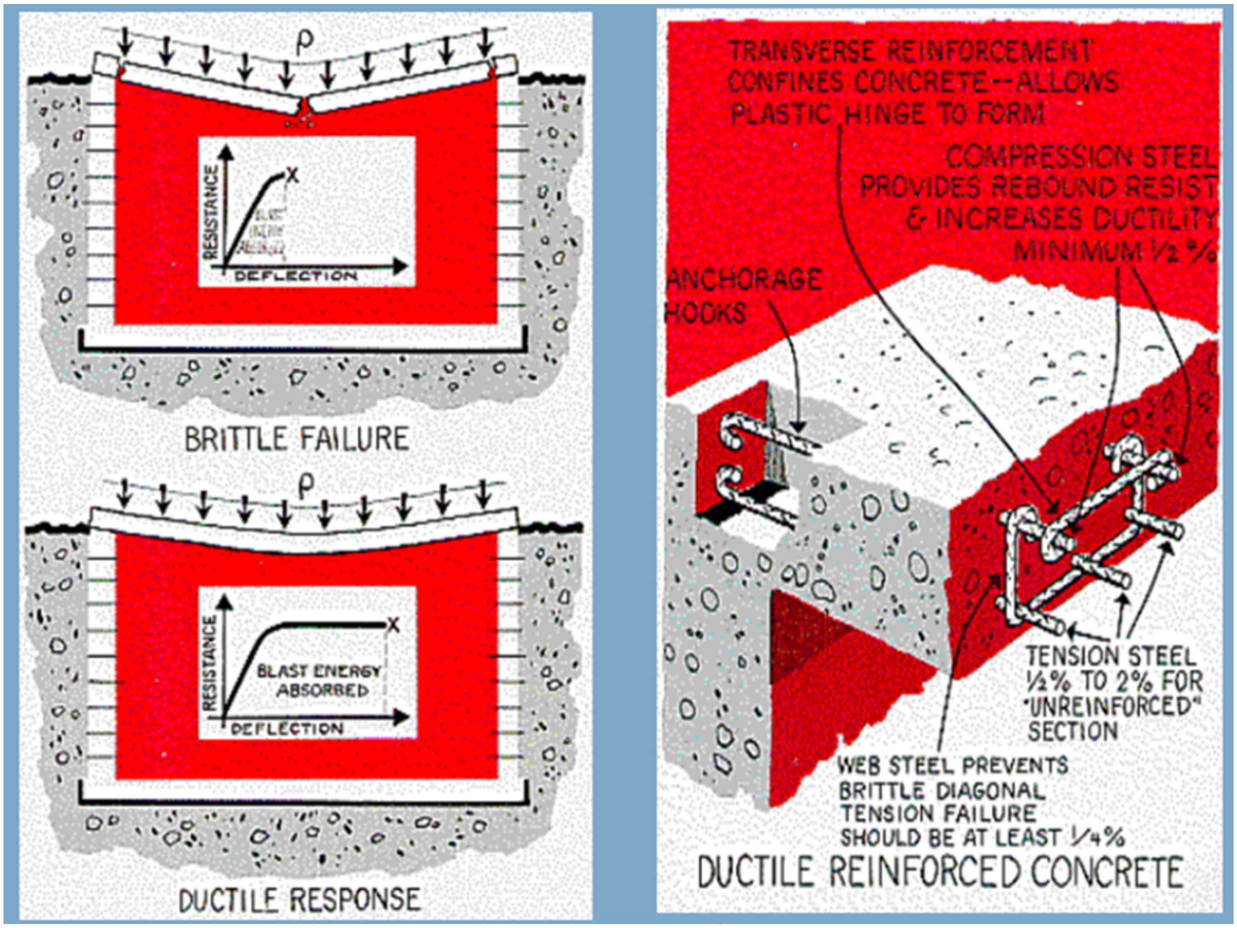


Figure 16. Ductile Structural Elements

Acceptable Damage Levels

Minor: Non-structural failure of building elements as windows, doors, and cladding.

Moderate: Structural damage is confined to a localized area and is usually repairable. Structural failure is limited to secondary structural members, such as beams, slabs and non-load bearing walls. However, if the building has been designed for loss of primary members, localized loss of columns may happen without initiating progressive collapse.

Major: Loss of primary structural components such as columns or transfer girders leads to loss of additional adjacent members that are adjacent or above the lost member. In this case, the building is usually not repairable.

Prevent Progressive Collapse & Catastrophic Failure

The aim of blast resistant building design is:

- ❑ Evaluation of the potential progressive collapse in new and existing buildings.
- ❑ To prevent the overall collapse of the building and fatal damages.

How to Prevent Progressive Collapse?

Alternate Load Path Method

This method is mainly recommended by the Department of Defense (DoD, 2007[1]) and General Services Administration (GSA, 2003[12]).

The philosophy of this method is to permit the occurrence of the local damage; however, the collapse of large portion of the structure is avoided by providing alternate load paths in the neighboring elements to redistribute the loads that were applied on the damaged components if they have designed sufficiently.

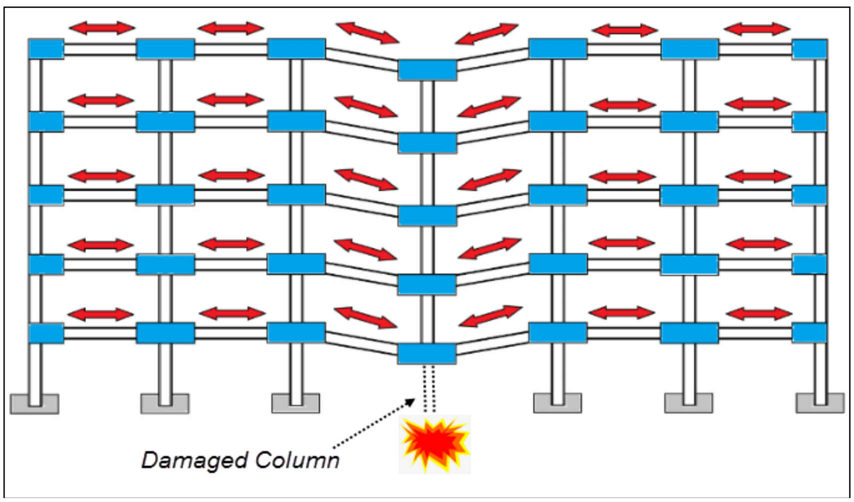


Figure 17. Alternate Load Path Method

Besides, in recent published research works, there are several ways to prevent progressive collapse as:

By embedding vertical steel cables in columns and hanging them at the top to a hat braced frame placed on the top of the building, which is seated on the top of the columns. (Hadi & Al-Rudaini[13])

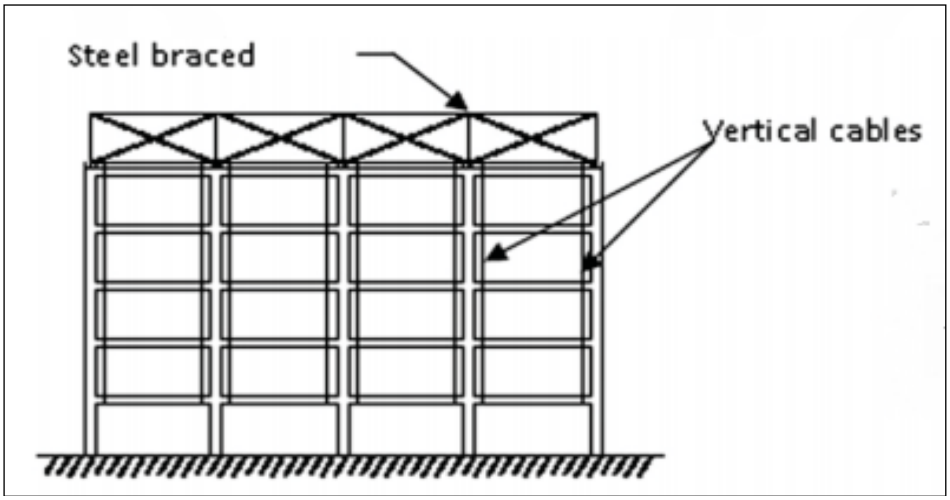


Figure 18. Vertical Steel Cables in Columns

Progressive collapse can be avoided for steel and RC structures if the depth of the beams around the removed column is MORE than span/15 and span/12, respectively. (Izadifard, 2014[14])

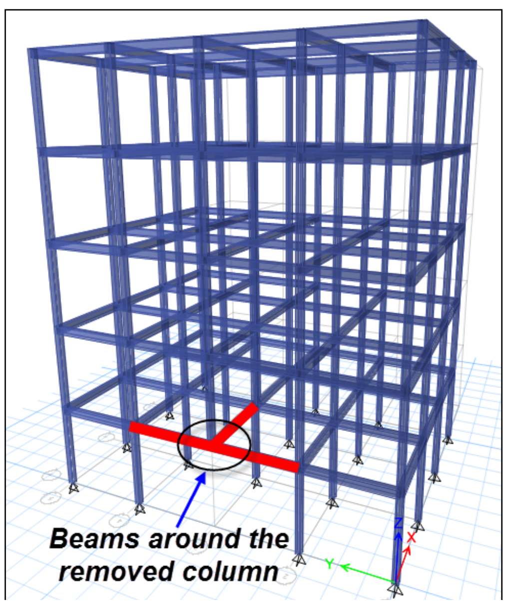


Figure 19. Beams Around the Removed Column

ASL[15] investigated a new way to prevent progressive collapse of floors, by placing steel cables inside the concrete floor slabs for new construction, or adding the cables under the slab for existing structures as a measure of retrofit. The main role of these cables is to prevent progressive collapse of the floor in the event of loss of one of the columns.

The following figure shows the application of this concept in a building. When a single column is removed and the floor starts to collapse, the steel cable prevents the collapse and transfers the load of the floor to neighboring columns and rest of the structures. Since cables are used in every floor, the loads of all floors above the removed column will be transferred to the adjacent columns. As a result, although the floors might have relatively large deformations in the order of 40-60 centimeters, the full progressive collapse and pan-caking of the floors are prevented.

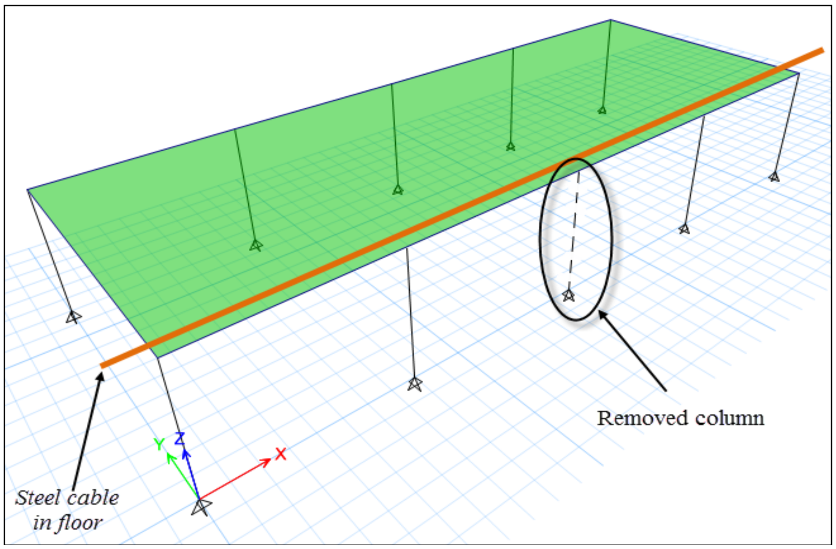
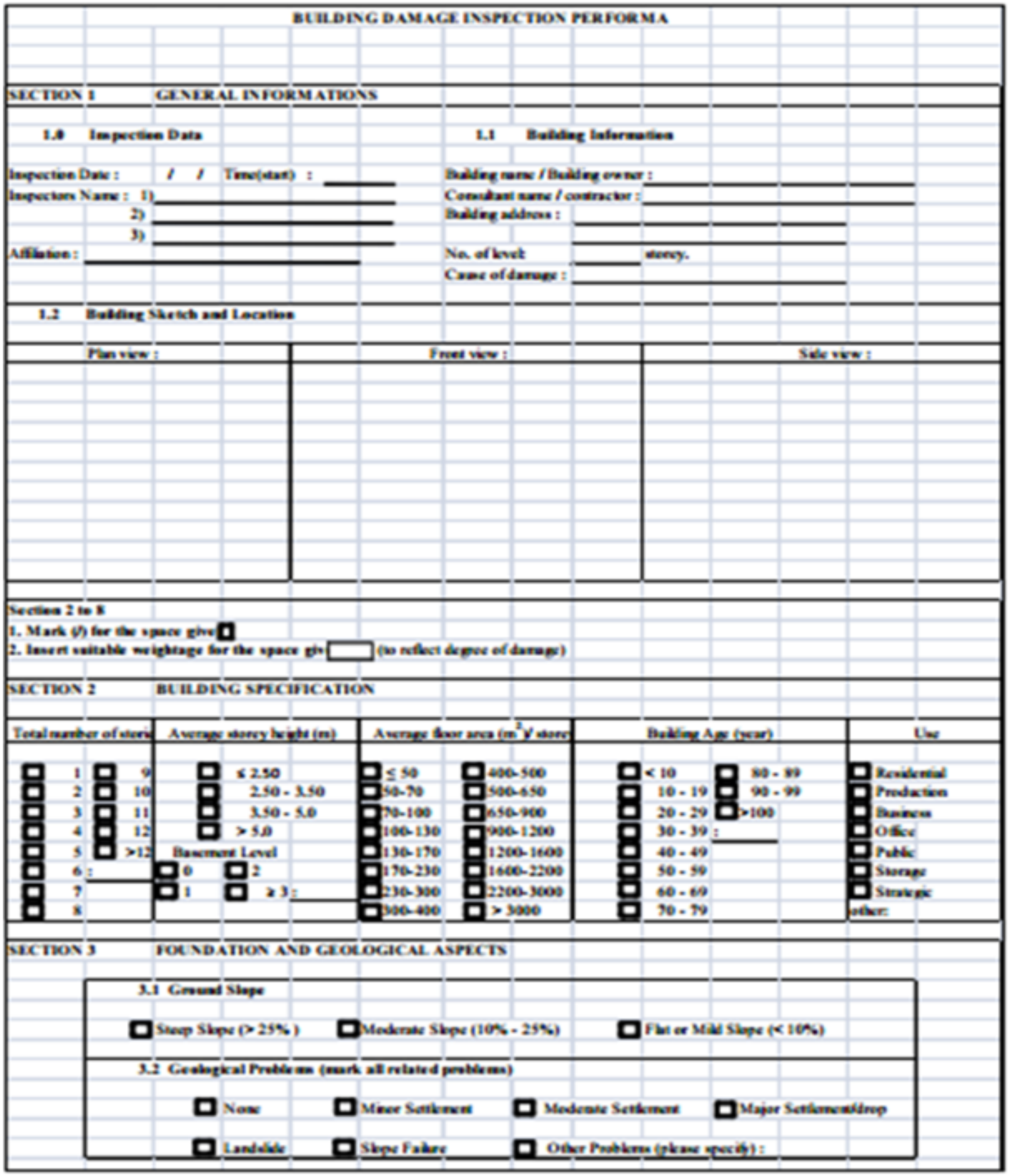


Figure 20. Placement of Steel Cables

Damage Evaluation Forms

For building subjected to blast loading, Norazman et al.[16] suggested the use of damage evaluation form in evaluating damaged structures due to various reasons such as act of terrorism.

This form is effective, and gives a detailed inspection view and could be used as a guide for decision making and planning for rehabilitation work.



BUILDING DAMAGE INSPECTION PERFORMA

SECTION 1 GENERAL INFORMATIONS

1.0 Inspection Data

Inspection Date : / / Time(start) : ______
Inspectors Name : 1) ______
2) ______
3) ______
Affiliation : ______

1.1 Building Information

Building name / Building owner : ______
Consultant name / contractor : ______
Building address : ______
No. of level: ______ storey.
Cause of damage : ______

1.2 Building Sketch and Location

Plan view :	Front view :	Side view :

Section 2 to 8
1. Mark (/) for the space give ☐
2. Insert suitable weightage for the space giv ☐ (to reflect degree of damage)

SECTION 2 BUILDING SPECIFICATION

Total number of storeys		Average storey height (m)	Average floor area (m²)/ storey		Building Age (year)		Use
☐ 1	☐ 9	☐ ≤ 2.50	☐ ≤ 50	☐ 400-500	☐ < 10	☐ 80 - 89	☐ Residential
☐ 2	☐ 10	☐ 2.50 - 3.50	☐ 50-70	☐ 500-650	☐ 10 - 19	☐ 90 - 99	☐ Production
☐ 3	☐ 11	☐ 3.50 - 5.0	☐ 70-100	☐ 650-900	☐ 20 - 29	☐ >100	☐ Business
☐ 4	☐ 12	☐ > 5.0	☐ 100-130	☐ 900-1200	☐ 30 - 39	: ______	☐ Office
☐ 5	☐ >12	Basement Level	☐ 130-170	☐ 1200-1600	☐ 40 - 49		☐ Public
☐ 6 : ______		☐ 0 ☐ 2	☐ 170-230	☐ 1600-2200	☐ 50 - 59		☐ Storage
☐ 7		☐ 1 ☐ ≥ 3 : ______	☐ 230-300	☐ 2200-3000	☐ 60 - 69		☐ Strategic
☐ 8			☐ 300-400	☐ > 3000	☐ 70 - 79		other:

SECTION 3 FOUNDATION AND GEOLOGICAL ASPECTS

3.1 Ground Slope

☐ Steep Slope (> 25%) ☐ Moderate Slope (10% - 25%) ☐ Flat or Mild Slope (< 10%)

3.2 Geological Problems (mark all related problems)

☐ None ☐ Minor Settlement ☐ Moderate Settlement ☐ Major Settlement/drop
☐ Landslide ☐ Slope Failure ☐ Other Problems (please specify) :

Figure 21. Example of an Evaluation Form

Location1:

SECTION 4 — DAMAGE TO STRUCTURAL ELEMENT AND THE EMERGENCY MEASURES

Level: **Location:**

Damage level and extension / Structural component	Extend of Damages	Emergency measures			
	Weightage	None	Repair	Protective Support	Remove
Load Bearing wall	☐	☐	☐	☐	☐
Column	☐	☐	☐	☐	☐
Beam	☐	☐	☐	☐	☐
Staircase	☐	☐	☐	☐	☐
Slab	☐	☐	☐	☐	☐
Roof Structure	☐	☐	☐	☐	☐

Weightage :- **Total:** ________

1 = None 2 = Light 3 = Moderate 4 = Serious

SECTION 5 — DAMAGE TO NON-STRUCTURAL ELEMENT AND THE EMERGENCY MEASURES

Level: **Location:**

Damage level and extension / Non-structural component	Extend of Damages	Emergency measures			
	Weightage	None	Repair	Protective Support	Remove
Interior Wall	☐	☐	☐	☐	☐
Exterior Wall	☐	☐	☐	☐	☐
Partitions	☐	☐	☐	☐	☐
Electrical system	☐	☐	☐	☐	☐
Plumbing System	☐	☐	☐	☐	☐

Weightage :- **Total:** ________

1 = None 2 = Light 3 = Moderate 4 = Serious

Note: Section 4 and Section 5 to be repeated for every location assessed.

Location2:

SECTION 4 — DAMAGE TO STRUCTURAL ELEMENT AND THE EMERGENCY MEASURES

Level: **Location:**

Damage level and extension / Structural component	Extend of Damages	Emergency measures			
	Weightage	None	Repair	Protective Support	Remove
Load Bearing wall	☐	☐	☐	☐	☐
Column	☐	☐	☐	☐	☐
Beam	☐	☐	☐	☐	☐
Staircase	☐	☐	☐	☐	☐
Slab	☐	☐	☐	☐	☐
Roof Structure	☐	☐	☐	☐	☐

Weightage :- **Total:** ________

1 = None 2 = Light 3 = Moderate 4 = Serious

SECTION 5 — DAMAGE TO NON-STRUCTURAL ELEMENT AND THE EMERGENCY MEASURES

Level: **Location:**

Damage level and extension / Non-structural component	Extend of Damages	Emergency measures			
	Weightage	None	Repair	Protective Support	Remove
Interior Wall	☐	☐	☐	☐	☐
Exterior Wall	☐	☐	☐	☐	☐
Partitions	☐	☐	☐	☐	☐
Electrical system	☐	☐	☐	☐	☐
Plumbing System	☐	☐	☐	☐	☐

Weightage :- **Total:** ________

1 = None 2 = Light 3 = Moderate 4 = Serious

Note: Section 4 and Section 5 to be repeated for every location assessed.

Figure 22. Example of an Evaluation Form

SECTION 6 DAMAGE CLASSIFICATION

Total Weightage (Section 4 & 5) = ______ Total Location Assessed = ______

Damage Index = Total Weightage x Total Location Assessed / Total Location x 11 (criteria)

Damage Index = ______

Damage Index	Damage Classification	Building Usage
> 3	Red	Unsafe
2 - 3	Yellow	Limited
< 2	Green	Safe

SECTION 7 EMERGENCY ACTION FOR THE WHOLE BUILDING

Emergency Action
☐ Minor repair
☐ Remove hazardous materials from building
☐ Protect building from progressive collapse
☐ Immediate Demolition

SECTION 8 EQUIPMENT UTILISED FOR DAMAGE ASSESSMENT

Damage Assessment Tools
☐ Schmidt Rebound Hammer
☐ Pundit Test
☐ Electromagnetic Cover Meter
☐ Sound Wave Hammer
☐ Core Test
☐ Other Test:

SECTION 9 INSPECTORS SUMMARY

1. Ground Condition : ______

2. Structural Condition : ______

3. Propose Rehabilitation : ______

4. Other Comment : ______

Completion Time: ______ Date: ______

Verified by		
Head of Team	Team Member 1	Team Member 2

Figure 23. Example of an Evaluation Form

Example Application:

Evaluation of blast-damaged concrete building according to GSA guidelines.

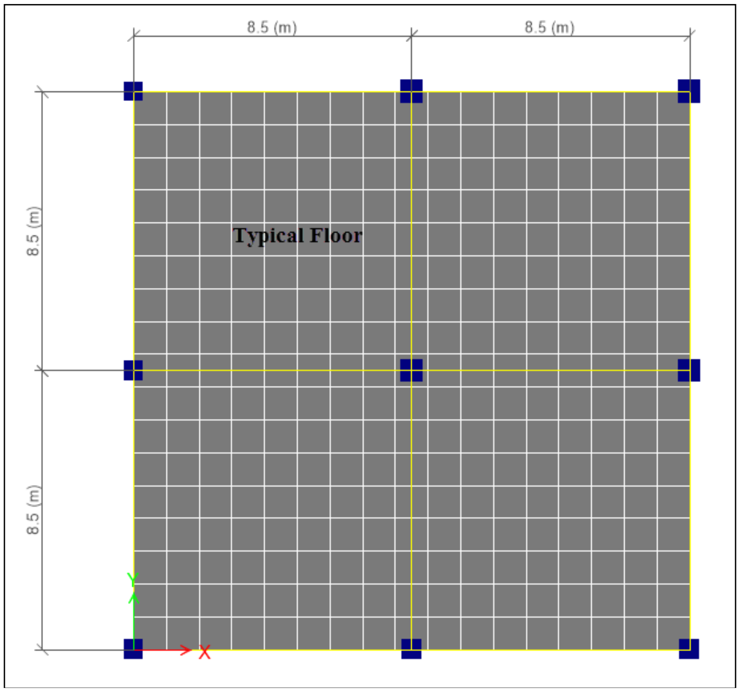


Figure 24. Example Application – Floor Dimensions

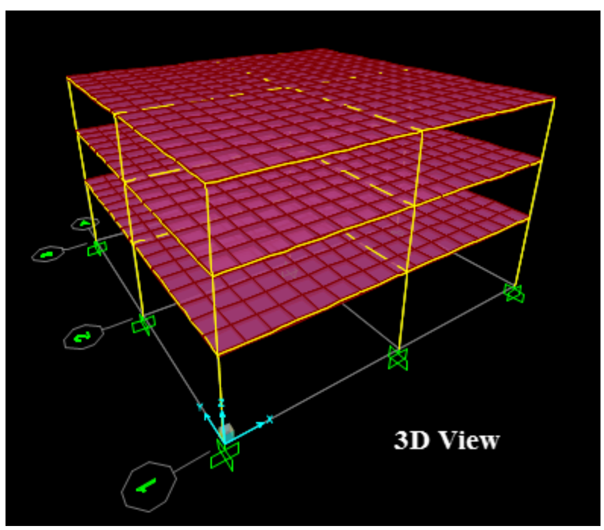


Figure 25. Example Application - 3D View

Gravity loads were taken as:

- Covering = 0.15 t/m^2
- Walls = 1.35 t/m acting on beams
- LL= 0.3 t/m^2

Dimensions and reinforcement of edge beams and typical columns in Model 1 at the ground floor level designed according to ACI 318-05.

		Dimensions (in. × in.)	Reinforcement (in.^{2})
Edge Beam Spans	Exterior	14 × 24	2.58 (Top) 1.24 (Bottom)
	Interior	14 × 22	2.37 (Top) 1.14 (Bottom)
Columns	Corner	22 × 22	4.84
	Exterior	22 × 22	8.75
	Interior	26 × 26	30.87

Figure 26. Dimensions and Reinforcements of Beams and Columns

The GSA[12] recommendations state the following scenarios:

1. Remove a load bearing element (column) near or at the middle of a longer side.
2. Remove a load bearing element near or at the middle of a shorter side.
3. Remove a load bearing element at the corner (This scenario was selected in this example)

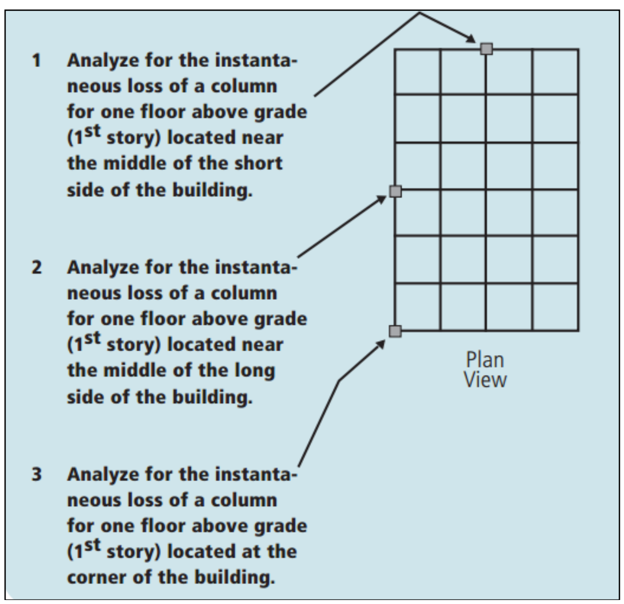


Figure 27. Example Application - Recommendations

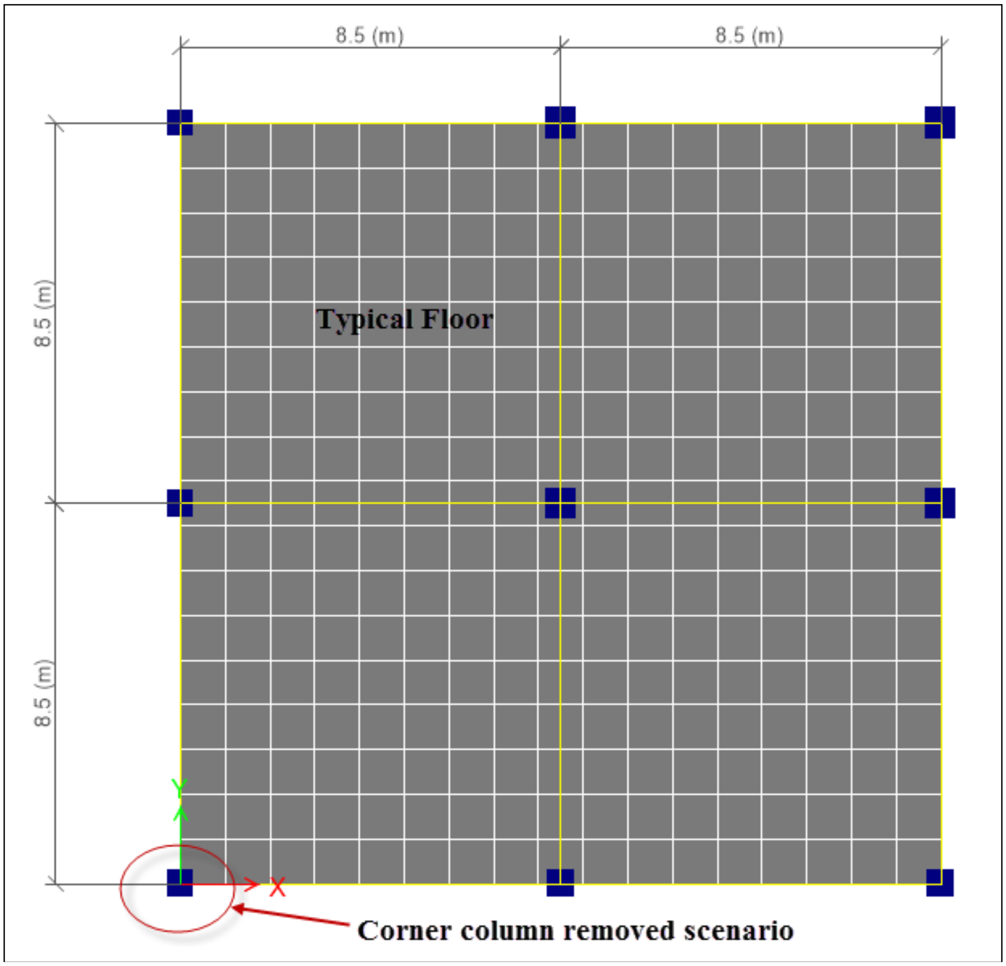


Figure 28. Example Application - Corner Column Removed

Steps of Nonlinear Dynamic Analysis According to GSA Guidelines

The nonlinear dynamic collapse analysis is needed to observe the formulation of plastic hinges through the structure, and the failed elements.

- **Step 1:** Prepare the three dimensional model in a computer. Perform concrete design and determine the reinforcement to be provided in members.

- **Step 2:** Define and assign plastic hinges to beams (at both ends, at 0.5 of span, at 0.3 of span & at 0.7 of span) and columns (at both ends).

- **Step 3:** All loads to be used in this analysis are as per the load combinations DL+0.25LL defined in GSA guidelines, where DL is the dead loads and LL is the live loads and define non-linear dynamic case.

- **Step 4:** SAP 2000 V. 21[17] can do *dynamic collapse analysis* to model progressive collapse. Nonlinear dynamic analysis case for column removal has been defined in SAP2000, as shown in the following figure.

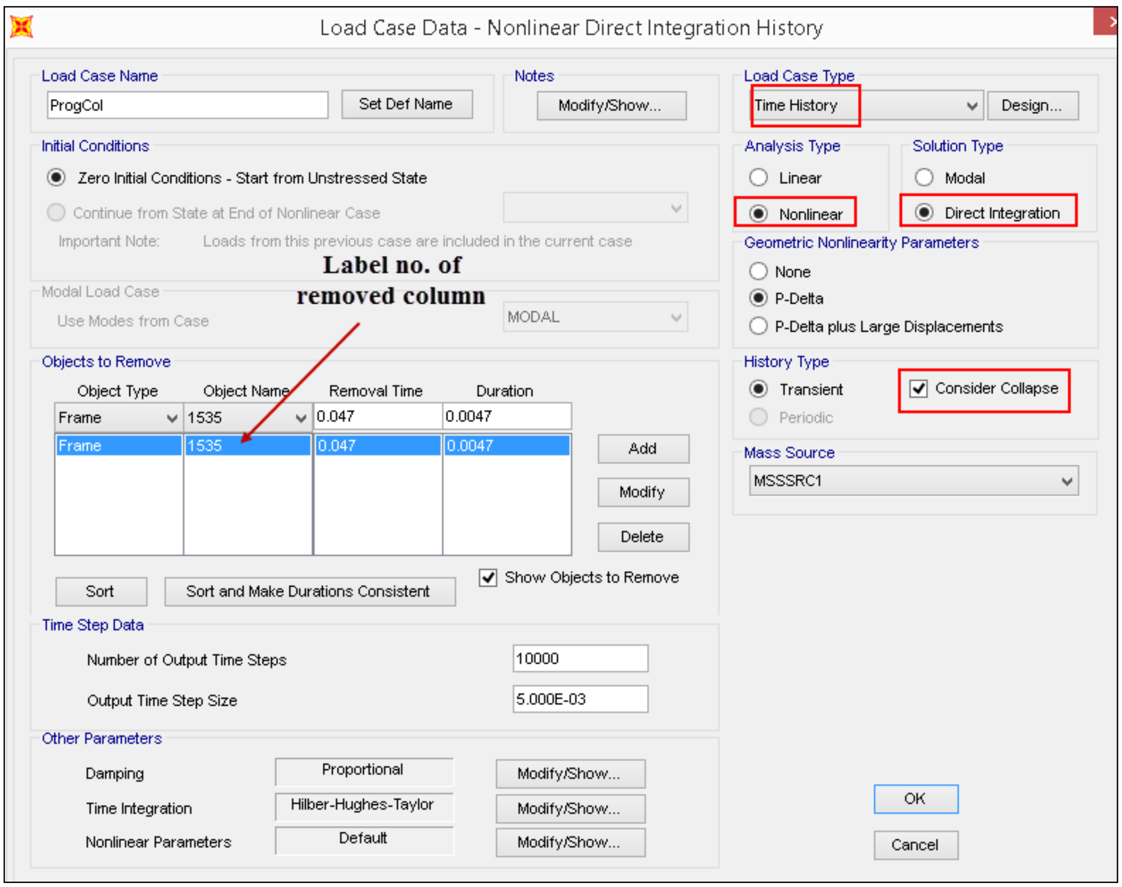


Figure 29. Nonlinear Dynamic Analysis for Column Removal

- **Step 5:** Observe the hinge formation status for all frame members at failure.

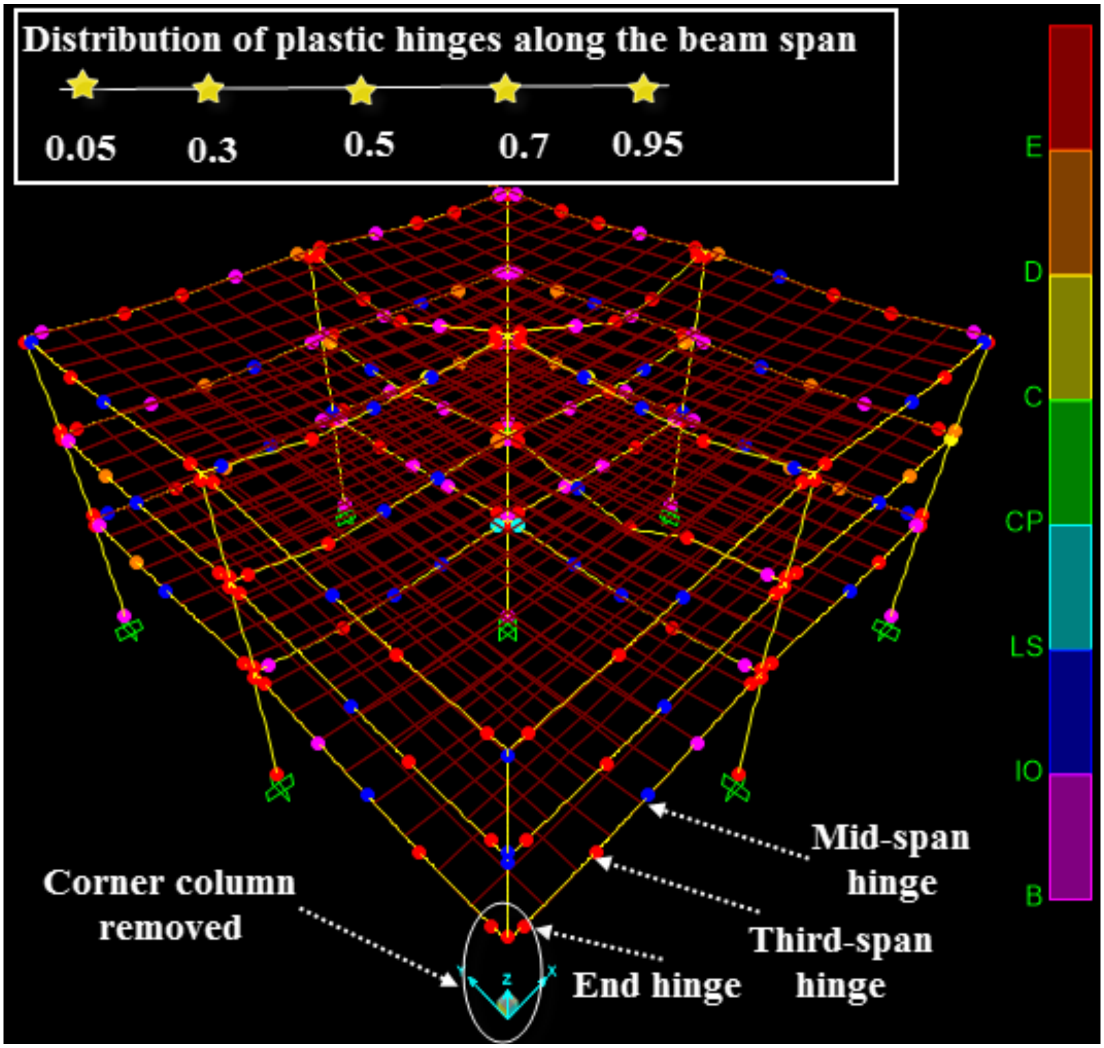


Figure 30. Appearance of Plastic Hinges in Beams and Columns

Damage Limits: According to FEMA-356[18], when the plastic hinge rotations are more than 0.025 radians for any member, it is considered as COLLAPSED (beyond the CP, collapse prevention state).

Also, according to Egyptian Specifications for Blast-Resistant buildings[19], the permissible damage area due to the loss of an external column must be smaller than 70 m^2, (the damaged area of the slab panel above the removed column equals 8.5*8.5 = 72 m^2)

Summary & Recommendations: The plastic hinges are spread in all beams and columns as shown in above figure. Values of most plastic hinge rotations for most members for this scenario are bigger than 0.025, hence, collapse will occur. Consequently, overall progressive collapse is expected for this structure.

Application of Damage Evaluation Forms for this Case

Location **1**

SECTION 4 **DAMAGE TO STRUCTURAL ELEMENT AND THE EMERGENCY MEASURES**

Level: ground **Location:** removed column side

Damage level and extension / **Structural component**	Extend of Damages / Weightage	None	Repair	Protective Support	Remove
Load Bearing wall		☐	☐	☐	☐
Column	4	☐	☐	☐	☒
Beam	4	☐	☐	☐	☒
Staircase		☐	☐	☐	☐
Slab	4	☐	☐	☐	☒
Roof Structure		☐	☐	☐	☐
Weightage :- **Total:**	12				

1 = None 2 = Light 3 = Moderate 4 = Serious

SECTION 5 **DAMAGE TO NON-STRUCTURAL ELEMENT AND THE EMERGENCY MEASURES**

Level: ground **Location:** removed column side

Damage level and extension / **Non-structural component**	Extend of Damages / Weightage	None	Repair	Protective Support	Remove
Interior Wall	4	☐	☐	☐	☒
Exterior Wall	4	☐	☐	☐	☒
Partitions	4	☐	☐	☐	☒
Electrical system	4	☐	☐	☐	☒
Plumbing System	4	☐	☐	☐	☒
Weightage :- **Total:**	20				

1 = None 2 = Light 3 = Moderate 4 = Serious

Figure 31. Damage Evaluation Form - Location 1

Location2:

SECTION 4 **DAMAGE TO STRUCTURAL ELEMENT AND THE EMERGENCY MEASURES**

Level: first floor **Location:** removed column side

Structural component \ Damage level and extension	Extend of Damages (Weightage)	Emergency measures: None	Repair	Protective Support	Remove
Load Bearing wall		☐	☐	☐	☐
Column	4	☐	☐	☒	☐
Beam	4	☐	☐	☒	☐
Staircase		☐	☐	☐	☐
Slab	4	☐	☐	☒	☐
Roof Structure		☐	☐	☐	☐
Weightage :- **Total:**	12				

1 = None 2 = Light 3 = Moderate 4 = Serious

SECTION 5 **DAMAGE TO NON-STRUCTURAL ELEMENT AND THE EMERGENCY MEASURES**

Level: first floor **Location:** removed column side

Non-structural component \ Damage level and extension	Extend of Damages (Weightage)	Emergency measures: None	Repair	Protective Support	Remove
Interior Wall	4	☐	☐	☐	☒
Exterior Wall	4	☐	☐	☐	☒
Partitions	4	☐	☐	☐	☒
Electrical system	3	☐	☐	☒	☐
Plumbing System	3	☐	☐	☒	☐
Weightage :- **Total:**	18				

1 = None 2 = Light 3 = Moderate 4 = Serious

Figure 32. Damage Evaluation Form - Location 2

Location 3

SECTION 4 **DAMAGE TO STRUCTURAL ELEMENT AND THE EMERGENCY MEASURES**

Level: second floor **Location:** removed column side

Structural component \ Damage level and extension	Extend of Damages (Weightage)	Emergency measures: None	Repair	Protective Support	Remove
Load Bearing wall		☐	☐	☐	☐
Column	4	☐	☐	☒	☐
Beam	4	☐	☐	☒	☐
Staircase		☐	☐	☐	☐
Slab	3	☐	☐	☒	☐
Roof Structure		☐	☐	☐	☐
Weightage :- **Total:**	11				

1 = None 2 = Light 3 = Moderate 4 = Serious

SECTION 5 **DAMAGE TO NON-STRUCTURAL ELEMENT AND THE EMERGENCY MEASURES**

Level: second floor **Location:** removed column side

Non-structural component \ Damage level and extension	Extend of Damages (Weightage)	Emergency measures: None	Repair	Protective Support	Remove
Interior Wall	4	☐	☐	☐	☒
Exterior Wall	4	☐	☐	☐	☒
Partitions	4	☐	☐	☐	☒
Electrical system	3	☐	☐	☒	☐
Plumbing System	3	☐	☐	☒	☐
Weightage :- **Total:**	18				

1 = None 2 = Light 3 = Moderate 4 = Serious

Figure 33. Damage Evaluation Form - Location 3

Location similar locations

SECTION 4 **DAMAGE TO STRUCTURAL ELEMENT AND THE EMERGENCY MEASURES**

Level: **Location:**

Damage level and extension / Structural component	Extend of Damages Weightage	Emergency measures: None	Repair	Protective Support	Remove
Load Bearing wall		☐	☐	☐	☐
Column	4	☐	☐	☒	☐
Beam	4	☐	☐	☒	☐
Staircase		☐	☐	☐	☐
Slab	3	☐	☐	☒	☐
Roof Structure		☐	☐	☐	☐

Weightage :- **Total:** 11

1 = None 2 = Light 3 = Moderate 4 = Serious

SECTION 5 **DAMAGE TO NON-STRUCTURAL ELEMENT AND THE EMERGENCY MEASURES**

Level: **Location:**

Damage level and extension / Non-structural component	Extend of Damages Weightage	Emergency measures: None	Repair	Protective Support	Remove
Interior Wall	3	☐	☐	☒	☐
Exterior Wall	3	☐	☐	☒	☐
Partitions	3	☐	☐	☒	☐
Electrical system	2	☐	☒	☐	☐
Plumbing System	2	☐	☒	☐	☐

Weightage :- **Total:** 13

1 = None 2 = Light 3 = Moderate 4 = Serious

Figure 34. Damage Evaluation Form - Similar Locations

SECTION 6 **DAMAGE CLASSIFICATION**

→ 12+20+12+18+11+18+(11+13)*9

Total Weightage (Section 4 & 5) = 307 Total Location Assessed = 12

Damage Index = $\frac{\text{Total Weightage x Total Location Assessed}}{\text{Total Location x 11 (criteria)}} = \frac{307 * 12}{12 * 11}$

Damage Index = 27.9

Damage Index	Damage Classification	Building Usage
> 3	Red	Unsafe
2 - 3	Yellow	Limited
< 2	Green	Safe

SECTION 7 **EMERGENCY ACTION FOR THE WHOLE BUILDING**

Emergency Action
☐ Minor repair
☐ Remove hazardous materials from building
☐ Protect building from progressive collapse
☐ Immediate Demolition

Figure 35. Damage Evaluation Procedure for Building Subjected to Blast Impact

References

1. DoD. (2007a). DoD Minimum Antiterrorism Standards for Buildings, UFC 4-010-01
2. Kontek Industries. (2008) “Homeland Security/Force Protection: Barrier Systems” Kontek Industries <http://www.kontekindustries.com> (June 15, 2008).
3. Crawford, J. E., and Lan, S. (2006) “Blast Barrier Design and Testing.” ASCE Structures Congress 2006: Structural Engineering and Public Safety – Proceedings of the 2006 Structures Congress, Long Beach, CA, 26-36.
4. Federal Emergency Management Agency(FEMA), December 2003, Primer for Design of Buildings to mitigate Terrorist Attacks, March 12, 2012
5. Mao, L., Barnett, S.,Tyas, A.,Warren, J., Schleyer, G., and Zaini, S.,(2015), Response of Small Scale Ultra High Performance Fibre Reinforced Concrete Slabs to Blast Loading, Construction and Building Materials,93:822-830p
6. Barnett SJ et al..Blast Tests of Ultra High Performance Fibre Reinforced Concrete Panels, Proc Institute of Civil Engineering, Construction Materials,2010 ,163(3);127–129p
7. *Ibrahim M. Metwally* , "Robustness of Full Scale CFDST Columns in filled with UHPC Under Blast Loading", Journal of Advances in Civil Engineering and Management Volume 1 Issue 1, 2018
8. Schleyer GK, Barnett SJ, Millard SG, Rebentrost M, Wight G.,(2011), UHPFRC Panel Testing, StructuralEngineering,89(23/24:34– 39p.
9. Melançon, C. ,(2015), Effect of High Performance Concrete and Steel Materials on The Blast Performance of Reinforced Concrete One-Way Slabs, M.Sc. Thesis, , University of Ottawa, 215p.
10. Peyman Beiranvand, Fereydoon Omidinasab, Marziye sadate Moayer, Shahpoor Mehdipour, Mohammad Zarei, " Finite Element Analysis for CFST Columns under Blast Loading", Journal of Applied and Computational Mechanics, Vol. 3, No. 4, (2017)
11. Zhang, F. ; Wu, C;Wang, H.; Zhou, Y.,(2015), Numerical Simulation of Concrete Filled Steel Tube Columns Against BLAST Loads, Thin-Walled Structures 92:82–92p.
12. GSA. (2003). “Progressive collapse analysis and design guidelines for new federal office buildings and major modernization projects” , General Services Administration (GSA). Washington. D.C.
13. Muhammad N. S. Hadi, and Thaer M. Saeed Alrudaini" New Building Scheme to Resist Progressive Collapse", JOURNAL OF ARCHITECTURAL ENGINEERING, ASCE / DECEMBER 2012
14. Ramezan Ali Izadifard, " An Efficient Method to Prevent Progressive Collapse of Steel and RC Buildings", World Journal of Environmental Biosciences, 2016.
15. Astaneh-Asl , "Progressive Collapse Prevention in New and Existing Buildings", Technical and Educational Website of Iranian Engineers, 2015

16. Norazman M Nor , M. Zainuddin Musa , Neza Ismail , M. Alias Yusof , Hapsa Husen , "Damage Evaluation Procedure for Building Subjected to Blast Impact", European Journal of Scientific Research, Vol.39 No.3, 2010
17. SAP2000 software. Computers and Structures-Inc. Berkeley, CA
18. Federal Emergency Management Agency(FEMA) 356: Prestandard and Commentary for the Seismic Rehabilitation of Buildings, Nov. 2000
19. Egyptian Specifications for Blast-Resistant buildings (Spec. 905), HBRC, 2017