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Analysis and Assessment of RC Structures Exposed to Explosions

Course No: S01-012 Credit: 1 PDH

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Protective Design Strategy of Blast-Resistant Structures

Reduce Blast Demands, HOW?

The Main Strategy for blast-resistance structures design is to reduce <u>blast demands</u>, 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 <u>standoff distances</u> against external attacks.



Figure 1. Standoff Distance







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 <u>massive concrete barriers</u> (Kontek 2008^[2]), <u>concrete enclosed with steel plates</u> (Crawford and Lan 2006^[3]), and <u>soil filled corrugated metal</u> (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 <u>designed sufficiently</u>.



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.

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Figure 21. Example of an Evaluation Form

Location1:

			evel:	Location:	
Damage level and	Extend of			Emergency measures	
extension	Damages				
Structural		None	Repair	Protective Support	Remove
component	Weightage				
Load Bearing wall					
Column			-		
Beam					-
Staircase					
Slab					
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Location2:

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extension	Damages				
structural		None	Repair	Protective Support	Remove
	Weightage				
Load Bearing wall					8
Column			-		
Beam					
Staircase					
Slab					
Roof Structure					•
cightage :- Total:					
1 = None 2 = Light 3	= Moderate 4 =	Serious			
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ion- tructural amponent terior Wall terior Wall tritions critical system rightage :- Total:	Weightage		Repair	Protective Support	Remove

Figure 22. Example of an Evaluation Form

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	101	al Location x 11 (criteria)			
Da	mage Index =				
	Damage Index	Damage Classification	Building Usage		
	>3	Red	Unsafe		
	2-3	Yellow	Limited		
	<2	Green	Safe		
SECTION 7	EMERCENCYAC	TION FOR THE WHOLE BUIL	UNING		
SECTION 7	EMERGENCIAU	HON FOR THE WHOLE BUI	LDING		
	Em	ergency Action			
	Minor repa	ir 🛛			
	Remove ha	zardous materials from building			
	Protect build	kling from progressive collapse			
	Immediate	Demolition			
SECTION 8	FOURMENTIT	ISED FOR DAMAGE ASSES	SMENT		
SECTIONS	EQUIPMENT CT	LISED FOR DAMAGE ASSES	SMEAT		
	Dan	nage Assessment Tools			
	Schmidt Re	ebound Hammer			
	Pundit Test	L I I I I I I I I I I I I I I I I I I I			
	Electromag	netic Cover Meter			
	Sound Wa	ve Hammer			
	Core Test				
	Uner rest				
SECTION 9	INSPECTORS SUM	IMARY			
1. Ground Condi	tion :				
2. Structural Cor	dition :				
3. Propose Reha	bilitation :				
4. Other Comme	nt :				
Comp	etion Time:	Date:			
		11			
	Head of Term	Team Man	abort 1	Team Member 2	
	ricad or ream	reand stell		- call included a	

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
- \Box Walls = 1.35 t/m acting on beams
- \Box LL= 0.3 t/m²

Dimensions and rein the ground floor leve	forcement of e l designed acco	lge beams and typical rding to ACI 318-05.	columns in Model 1 at
		Dimensions (in. \times 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 Interior	$\begin{array}{c} 22\times22\\ 26\times26 \end{array}$	8.75 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 <u>dynamic collapse analysis</u> to model progressive collapse. Nonlinear dynamic analysis case for column removal has been defined in SAP2000, as shown in the following figure.

Load Case Name		Notes		Load Case Type		
ProgCol	Set Def Name	M	odify/Show	Time History	✓ Design	
nitial Conditions				Analysis Type	Solution Type	
Zero Initial Conditions - Sta	rt from Unstressed State			🔘 Linear	🔘 Modal	
O Continue from State at End	of Nonlinear Case		\sim	 Nonlinear 	Oirect Integration	
Important Note: Loads fi	rom this previous case are inclu	uded in the curr	ent case	Geometric Nonlinea	rity Parameters	
	Label no. of			O None		
Modal Load Case	removed colum	in		P-Detta		
Use Modes from Case	/	MODAL	¥	P-Delta plus La	rge Displacements	
Objects to Remove				History Type		
Object Type Object N	lame Removal Time	Duration		Transient	Consider Collapse	
Frame 🗸 1535	0.047 0.0	047		Periodic		
Frame 1535	0.047 0.0	047	Add	Mass Source		
			Modify	MSSSRC1		
			Delete			
Sort Sort and M		✓ Show Obj	Delete ects to Remove			
Sort Sort and M	lake Durations Consistent	Show Obj	Delete ects to Remove			
Sort Sort and M	lake Durations Consistent	Show Obj	Delete ects to Remove			
Sort Sort and M Time Step Data Number of Output Time S	lake Durations Consistent	Show Obj 10000	Delete ects to Remove			
Sort Sort and M Time Step Data Number of Output Time S Output Time Step Size	lake Durations Consistent	✓ Show Obj 10000 5.000E-0	Delete ects to Remove			
Sort Sort and M Time Step Data Number of Output Time S Output Time Step Size Other Parameters	lake Durations Consistent	Show Obj 10000 5.000E-0	Delete ects to Remove			
Sort Sort and M Time Step Data Number of Output Time S Output Time Step Size Other Parameters Damping	lake Durations Consistent	Show Obj 10000 5.000E-0 Modify/S	Delete ects to Remove			
Sort Sort and M Time Step Data Number of Output Time S Output Time Step Size Other Parameters Damping Time Integration	lake Durations Consistent teps Proportional Hilber-Hughes-Taylor	Show Obj 10000 5.000E-0 Modify/S Modify/S	Delete ects to Remove		ОК	

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 m², (the damaged area of the slab panel above the removed column equals $8.5*8.5 = 72 \text{ m}^2$)

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.

	TAGE TO STRUCTUR	AL ELENIE	NT AND THE EN	IERGENCY MEASU	RES	
		1	Level: ground	Location:	<u>removed</u> col	umn side
Damage level an	d Extend of		I	Emergency measures		
extension	Damages					
Structural		None	Repair	Protective Support	Remove	
component	Weightage					
Load Bearing wall						
Column	4					
Beam	4					
Staircase						
Slab	4				P	
Roof Structure						
Vaiahtaga - T	atal: 12					
weightage :- I	otan:	-				
1 = None 2 = 1	ight 2 = Moderate 4 =	Serious				
1 = None 2 = 1	Light 3 = Moderate 4 =	Serious				
1 = None 2 = 1 SECTION 5 DAN	Light 3 = Moderate 4 =	Serious CTURAL EL	EMENT AND T	HE EMERGENCY M	EASURES	
1 = None 2 = 1 SECTION 5 DAM	Light 3 = Moderate 4 = MAGE TO NON-STRU	Serious CTURAL EL	EMENT AND T	HE EMERGENCY M	EASURES	umn side
1 = None 2 = 1 SECTION 5 DAM	Light 3 = Moderate 4 =	Serious CTURAL EL	EMENT AND T Level: <u>g</u> tound	HE EMERGENCY M Location: 1 Emergency measures	easures removed col	umn side
1 = None 2 = 1 SECTION 5 DAM Damage level an extension	Light 3 = Moderate 4 = MAGE TO NON-STRU ad Extend of Damages	Serious CTURAL EL	EMENT AND T Level: <u>grounc</u> I	HE EMERGENCY M Location: 1 Emergency measures	easures removed col	umn side
1 = Nonc 2 = 1 SECTION 5 DAM Damage level an extension structural	Light 3 = Moderate 4 = MAGE TO NON-STRU ad Extend of Damages	Serious CTURAL EL	EMENT AND T Level: ground I Repair	HE EMERGENCY M Location: 1 Emergency measures Protective Support	EASURES removed col	umn side
1 = Nonc 2 = 1 SECTION 5 DAM Damage level an extension structural component	Light 3 = Moderate 4 = MAGE TO NON-STRU ad Extend of Damages Weightage	Serious CTURAL EL	EMENT AND T Level: ground I Repair	HE EMERGENCY M Location: 1 Emergency measures Protective Support	EASURES removed col	umn side
1 = Nonc 2 = 1 SECTION 5 Damage level an extension structural component nterior Wall	Light 3 = Moderate 4 = MAGE TO NON-STRU ad Extend of Damages Weightage	CTURAL EL	EMENT AND T Level: ground I Repair	HE EMERGENCY M Location: 1 Emergency measures Protective Support	EASURES removed col	umn side
1 = None 2 = 1 SECTION 5 Damage level an extension structural component nterior Wall	Light 3 = Moderate 4 = MAGE TO NON-STRU ad Extend of Damages Weightage	CTURAL EL	EMENT AND T Level: ground I Repair	HE EMERGENCY M Location: 1 Emergency measures Protective Support	Remove	umn side
1 = None 2 = 1 SECTION 5 Damage level an extension structural component nterior Wall Partitions	Light 3 = Moderate 4 = MAGE TO NON-STRU ad Extend of Damages Weightage	CTURAL EL	EMENT AND T Level: ground Repair	HE EMERGENCY M Location: 1 Emergency measures Protective Support	Remove	umn side
1 = None 2 = 1 SECTION 5 Damage level an extension structural component nterior Wall Partitions Electrical system	Light 3 = Moderate 4 = MAGE TO NON-STRU ad Extend of Damages Weightage 4 4 4 4	CTURAL EL	EMENT AND T Level: ground Repair	HE EMERGENCY M Location: 1 Emergency measures Protective Support	Remove	umn side
1 = None 2 = 1 SECTION 5 Damage level an extension structural component nterior Wall Partitions Electrical system	Light 3 = Moderate 4 = MAGE TO NON-STRU ad Extend of Damages Weightage 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4	Serious CTURAL EL None	EMENT AND T Level: ground Repair	HE EMERGENCY M Location: 1 Emergency measures Protective Support	Remove	umn side
1 = None 2 = 1 SECTION 5 Damage level an extension structural component netrior Wall Startions Stectrical system Plumbing System Weightage :-	Light 3 = Moderate 4 = MAGE TO NON-STRU ad Extend of Damages Weightage 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 5 0 1 8 1 9 1 9 1 9 1 9 1 9 1 9 1 9 1 9 1 9	Serious CTURAL EL None	EM ENT AND T Level: ground Repair	HE EMERGENCY M Location: 1 Emergency measures Protective Support	Remove	umn side

Figure 31. Damage Evaluation Form - Location 1

Analysis and	Assessment o	of RC Structures	Exposed to	Explosions	- S01-012

SECTION 4	DAMAGE	TO STRUCTUR	RAL ELEM	ENT AND THE E	MERGENCY MEASU	URES	
				Level: first flo	Or Location:	removed co	lumn side
Damage leve	el and	Extend of			Emergency measures		
extension Structural		Damages					
			None	Repair	Protective Support	Remove	
		Weightage					
Load Bearing v	vall						
Column		4					
Beam		4					
Staircase							
Slab					8		
RoofStructu	re						
Weightage :-	Total:	12					1
1 = None	2 = Light 3	= Moderate 4 =	Serious				
DOTION 5		TO NON OTDU	CTUD II I			E LOUD DO	
SECTION 5	DAMAGE	TO NON-STRU	CIUKALI	Leweb first fl	THE EMERGENCY N	TEASURES	ump aida
Damagalau	land	Extand of		Level: IIISt II	Location:	removed col	
Damage leve		Damages			Emergency measures		
Non-	‴ ⊢	Damages	None	Renair	Protective Support	Remove	
component	\sim \vdash	Weightage	Trone	repair	rotecuve Support	Reniove	
nterior Wall	\rightarrow	4					
Exterior Wall		4	l d	H H	H H	- F	
Partitions							
Electrical system		2		Ō		õ	
Plumbing System				Ō		ō	
Vojahtago :-	Total:	10					
weightage							



Socution 5							
SECTION 4 D	AMAGE 1	FO STRUCTU	RAL ELEME	NT AND THE	EMERGENCY MEAS	SURES	
				Level: Secon	d HOOT Location	<u>removed co</u>	olumn side
Damage level	and	Extend of	of Emergency measures				
Structura	<u>ٰ</u> ل	Damages					
component			None	Repair	Protective Support	Remove	
		Weightage					
Load Bearing wa	all						
Column		4		5	1		
Beam		4					
Staircase							
Slab		3			-8-		
RoofStructure							
			-				
Weightage :- 1 = None 2	Total:		Serious				
Weightage :- 1 = None 2 SECTION 5 D	Total:	H Moderate 4 =	Serious	LEMENT AND	THE EMERGENCY	MEASURES	
Weightage :- 1 = None 2 SECTION 5 D	Total: = Light 3 =	- Moderate 4 =	Serious	LEMENT AND Level: Secon	THE EMERGENCY d floor Location	MEASURES	<u>l</u> umn side
Weightage :- 1 = None 2 SECTION 5 D Damage level	Total: = Light 3 = AMAGE 1 and	= Moderate 4 = FO NON-STRU Extend of	Serious	LEMENT AND Level: SECON	THE EMERGENCY d floof Location: Emergency measures	MEASURES : removed co	lumn side
Weightage :- 1 = None 2 SECTION 5 D Damage level extension	Total: = Light 3 = AMAGE 1 and	11 = Moderate 4 = FO NON-STRI Extend of Damages	Serious	LEMENT AND Level: SECON	THE EMERGENCY d flOOT Location: Emergency measures	MEASURES : removed co	lumn side
Weightage :- 1 = Nonc 2 SECTION 5 D Damage level extension structural	Total:	11 Moderate 4 = FO NON-STRI Extend of Damages	Serious	LEMENT AND Level: SeCOn Repair	THE EMERGENCY d flOOT Location Emergency measures Protective Support	MEASURES : removed co Remove	olumn side
Veightage :- 1 = None 2 SECTION 5 D Damage level extension structural component	Total:	11 = Moderate 4 = TO NON-STRU Extend of Damages Weightage	Serious UCTURAL EI None	LEMENT AND Level: SECOII Repair	THE EMERGENCY d floor Location: Emergency measures Protective Support	MEASURES : removed co Remove	olumn side
Veightage :- 1 = None 2 SECTION 5 D Damage level extension structural component nterior Wall	Total:	11 = Moderate 4 = FO NON-STRU Extend of Damages Weightage	Serious UCTURAL EI None	LEM ENT AND Level: SECOI Repair	THE EMERGENCY d floor Location: Emergency measures Protective Support	MEASURES removed cc Remove	lumn side
Veightage :- 1 = None 2 SECTION 5 D Damage level extension structural component nterior Wall Exterior Wall	Total:	11 Moderate 4 = TO NON-STRU Extend of Damages Weightage	Serious UCTURAL EI None	LEM ENT AND Level: Secon Repair	THE EMERGENCY d floor Location: Emergency measures Protective Support	MEASURES : removed cc Remove	lumn side
Weightage :- 1 = None 2 SECTION 5 D Damage level extension structural component interior Wall Exterior Wall	Total:	11 = Moderate 4 = FO NON-STRU Extend of Damages Weightage 4 4	Serious UCTURAL EI None	LEM ENT AND Level: Secon Repair	THE EMERGENCY d flOOT Location: Emergency measures Protective Support	MEASURES : removed cc Remove	lumn side
Weightage :- 1 = None 2 SECTION 5 D Damage level extension structural component interior Wall Exterior Wall Partitions Electrical system	Total:	11 = Moderate 4 = FO NON-STRU Extend of Damages Weightage 4 4 4 4 4 4 4 4 4 4 4 4 4	Serious UCTURAL EI None	LEMENT AND Level: S&COII Repair	THE EMERGENCY d flOOT Location: Emergency measures Protective Support	Remove	lumn side
Weightage :- 1 = None 2 SECTION 5 D Damage level extension structural component Interior Wall Partitions Electrical system Plumbing System	Total:	11 = Moderate 4 = TO NON-STRU Extend of Damages Weightage 4 4 4 4 4 4 4 4 4 4 4 4 4	Serious UCTURAL EI None	LEM ENT AND Level: Secon Repair	THE EMERGENCY d floor Location: Emergency measures Protective Support	MEASURES : removed cc Remove	olumn side

Figure 33. Damage Evaluation Form - Location 3

SECTION 4 DAMAG	E TO STRUCTUR	AL ELEMENT	FAND THE	EMERGENCY MEASU	RES	
		Le	evel:	Location:		
Damage level and	Extend of			Emergency measures		
extension	Damages					
Structural		None	Repair	Protective Support	Remove	
component	Weightage					
Load Bearing wall	Ľ					
Column	4					
Beam	4					
Staircase						
Slab				-		
RoofStructure						
Weightage :- Total:	11					
1 = None 2 = Light	3 = Moderate 4 =	Serious				
SECTION 5 DAMAG	E TO NON-STRU	CTURAL ELE	MENT AND	THE EMERGENCY M	EASURES	
		Le	vel:	Location:		
Damage level and	Extend of			Emergency measures		
Non- extension	Damages					
structural		None	Repair	Protective Support	Remove	
component	Weightage					
Interior Wall	3				0	
Exterior Wall						
Partitions						
Electrical system	2		P			
Plumbing System	2		-8-			
Weightage :- Total:	13					
1 = None 2 = Light	3 = Moderate 4 =	Serious				

Locationsimilar locations

Figure 34. Damage Evaluation Form - Similar Locations

SECTION 6	DAMAGE CLASS	SIFICATION	> 12+20+	12+18+11+18+(11+13)*9
Total W	eightage (Section 4 &	5) = 307 Total Locatio	n Assessed = 12	
Dam	age Index • Total We	ightage x Total Location Assesse	^d = <u>307 * 12</u>	
		fai Locaton x 11 (cheria)	12 * 11	
Dam	age Index <mark>= 27.9</mark>			
	Damage Index	Damage Classification	Building Usage	
	> 3	Red	Unsafe	
	2 - 3	Yellow	Limited	
	< 2	Green	Safe	
SECTION 7	EMERGENCY A	CTION FOR THE WHOLE B	UILDING	
	F	managency Action		
	Minor ret	air		
	Remove	hazardous materials from building		
	Protect h	uilding from progressive collapse		
	Immediat	e 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).
- 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
- 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.
- 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.
- 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