POST BLAST DAMAGE EVALUATION OF RC BUILDING

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مُسْـتَخْلَـص

منذ عام 2011م، العديد من المباني المدنية في البلدان العربية تعرضت إلى اضرار نتيجة قوى انفجار، و التي كانت لفترة طويلة ذات الاهتمام العسكري. لكن اليوم اصبح من المهم دراسة مثل هذا النوع من الأحمال الشديدة. إن الأهميه لا تنحصر على تصميم المباني لمقاومة أحمال الانفجار و إنما أيضاً يجب تقييم المباني المتضرره بعد الانفجار من ناحية قابلية الاستخدام و الامان في أقرب وقت ممكن. الغرض من هذه الدراسة هو تطوير منهجية لتقييم الضرر الناتج من الانفجار و تقييم الامان للمباني المشيدة من الخرسانة المسلحة. و لتحقيق هذا الهدف و نتيجة لاوجه الشبه بين قوى الزلازل و قوى الانفجار، فقد تم عمل دراسة مقارنه بينهما و من ثم تكييف طرق تقييم ضرر قوى الزلازل و تعديلها لتناسب تقييم الضرر الناتج من قوى الانفجار.

ABSTRACT

Since 2011, many civilian buildings in Arabian Countries exposed to damages due to explosion forces which have been for long time especially related to the military important. But today more important trend shall be taken towards such type of extreme load. The importance shall not only considered the design of the buildings to resist the blast loading but also damaged building after the explosion shall be evaluated for usability and safety as soon as possible. The purpose of this study is to develop a methodology for post-blast damage evaluations and safety assessment of reinforced concrete building. To meet this goal and due similar characteristics of the Blast and Seismic loadings, comparison study has been conducted. The post-earthquake damage evaluation methodologies have been adapted and modified for post-explosion damage.

Keywords: *Post-Blast Damage, Rapid Evaluation, Detailed Evaluation, Engineering Evaluation, Safety Assessment, RC building.*

1 Introduction

Blast is a sudden and rapid release of energy creating a pressure disturbance or blast wave radial propagating outward from the source. The source can be a high explosive that is used widely and intentionally by the terrorists and adversaries.

As the blast wave expands in air may impinges on building located within its path and then the building will be engulfed by shock pressures.

The magnitude and distribution of the blast loads on the structure arising from these pressures are a function of three factors: (1) explosive properties, namely type of explosive material, energy output (high or low order detonation), and weight of explosive; (2) the location of the detonation relative to the protective structures; and (3) the magnitude and reinforcement of the pressure by its interaction with the ground barrier, or the structure itself.

The blast can effect buildings in multiple way; air blast, drag, ground shock, primary and secondary fragmentation and Fire [1,2,3].

Following the events of the so-called Arabic Revolutions 2011, many civilian buildings have been exposing to the blast forces with tragic effects and consequences. Mitigation of secondary effects that may result an additional losses and injuries is an essential issue.

Many researches have studied to evaluate the post-explosion damage of structural elements (local impact) and global response of structures [4-7], but till now, standard or full procedure to evaluate the post-blast damage for usability and safety assessment is not available.

Post-blast damage evaluation and safety assessment are highly needed to:

- Ensure usability and safety of buildings
- Judge risk of the secondary collapse.
- Establish a proper reconstruction strategy for long term usability.
- Assess of overall economic loss or all overall funding needed for reconstruction.

1.1 Objectives

- To develop a procedure for post-blast damage evaluation of RC buildings.
- To define damage grade classification criteria of individual element.
- To assess the overall damage rating of the building.
- To develop a formal mechanism for inspection system and posting placards to effectively implement the quick inspection of system.
- To define a long term plan for building restoration.

1.2 Scope

This study will focus on damage evaluation procedure and classification for reinforced concrete low to medium rise residential buildings subjected to blast forces.

1.3 Methodology

In order to develop a reliable procedure for post-explosion damage evaluation the methodology shown in Figure 1 is followed. The blast characteristics were compared with seismic characteristics to determine the similarities and differences. The applicability check has been set considering the following points.

- The experiences of earthquake damage evaluation and safety assessment as a mature arena [10-16].
- Previous studies were made to the post-explosion damage evaluation of reinforced concrete [4,5,8].

Finally, starting from a review the existing different Guidelines Procedures of earthquake damage evaluation and safety assessment [10-16], the adaptation of post-earthquake damage evaluation of buildings to post-blast damage is introduced.

2 Blasts vs. Seismic Loading

Blast wave and seismic loading are two different type of extreme force that may cause structural failure. However, they share some common similarities [5, 8,9].

2.1 Similarities

1. Extreme dynamic loads with dynamic structural response.
2. Involve inelastic structural response to dissipate energy.
3. Performance based design: life safety issues as opposed to preventing structural damage & progressive collapse.
4. Structural integrity: includes ductility, continuity, and redundancy; balanced design.

5. Other considerations: Nonstructural damage and hazards.

2.2 Differences

1. Blast loading is due to a propagating pressure wave as opposed to ground shaking.
2. Blast results in direct pressure loading to structure; pressure is in all directions, whereas a seismic event is dominated by lateral load effects.
3. Blast effects are confined to structures in the immediate vicinity of event because pressure decays rapidly with distance.
4. Blast loading is of higher amplitude and very short duration compared with a seismic event.
5. Magnitude of blast loading is difficult to predict and not based on geographical location.
6. Progressive collapse is the most serious consequence of blast loading.
7. Distribution of ductility demand throughout the structure, while the seismic design prefer strong column-weak beam approach, the blast design provide strong beam for alternative load path (catenary action) to prevent collapse.
8. Slab failure is typical in blasts due to large surface area subjected to upward pressure not considered in gravity design.
9. Seismic analysis and design is mature compared with blast loading.
10. Seismic loading causes global response to building while blast loading causes localized response.
11. Blast loading is more difficult to be predicted than seismic loading.

2.3 The Applicability of Post-Seismic Damage Evaluation of Building to Post-Blast Damage;

The evaluation of damages of reinforced concrete building due exceptional loadings is approximately the same; however, there are some different characteristics of blast loading damages.

The procedures of post-earthquake damage evaluation of buildings could be adapted and used for post-explosion damage of buildings [5]. Table 1, gives the main remarkable points shall be taken in the consideration.

During the inspection of post-explosion damages, additional attention shall be taken for the secondary explosion that can happen. The explosion materials may have another effect and injuries.

Table 1: Comparison between Post-Blast and Seismic Evaluation

S/N	POST-BLAST EVALUATION	POST-SEISMIC EVALUATION
1	Local damages	Global damages
2	Pressure in all direction	Ground shaking
3	All Elements shall be evaluated	Focusing on Column and Walls
4	Based on the vicinity of explosion	Based on geographical location
5	Direct pressure to the element	Dominated by lateral load

3 Developed Procedure of Post-Blast Damage Evaluation

Figure 2 illustrates the developed procedure of post blast damage inspection and safety evaluation and posting process for RC buildings.

3.1 Terminologies

-**Damage**: Collapse, slip, crack, subsidence, undulation and inclination of ground caused by an explosion.

-**Degree of danger**: The degree of danger means the level of the danger that affects human life due to the destruction of building frames, and falling or tip-over of building components. There are three ranks of degree of danger, "unsafe", "limited entry", and "inspected", based on the damage levels of different parts of the object building.

-**Class of damage**: The class of damage means the level of explosion-caused destruction or deformation of buildings or objects attached thereto. There are three ranks of damage level, A, B, and C, in an ascending order, for the inspection of damaged buildings.

-Damage level: The damage level means the level of destruction of members and parts of reinforced concrete buildings. The "criterion on damage classification" defines five levels of destruction, I to V, in an ascending order according to the extent of damage.

-**Restoration**: Restoration is to recover or improve the structural performance, durability, and functions of buildings damaged by an explosion, including the following repair and strengthening.

-**Repair**: Repair is to recover the structural performance of damaged buildings to the original level (before the explosion).

-**Strengthening:** Strengthening is to improve the structural performance above the original level (before the explosion).

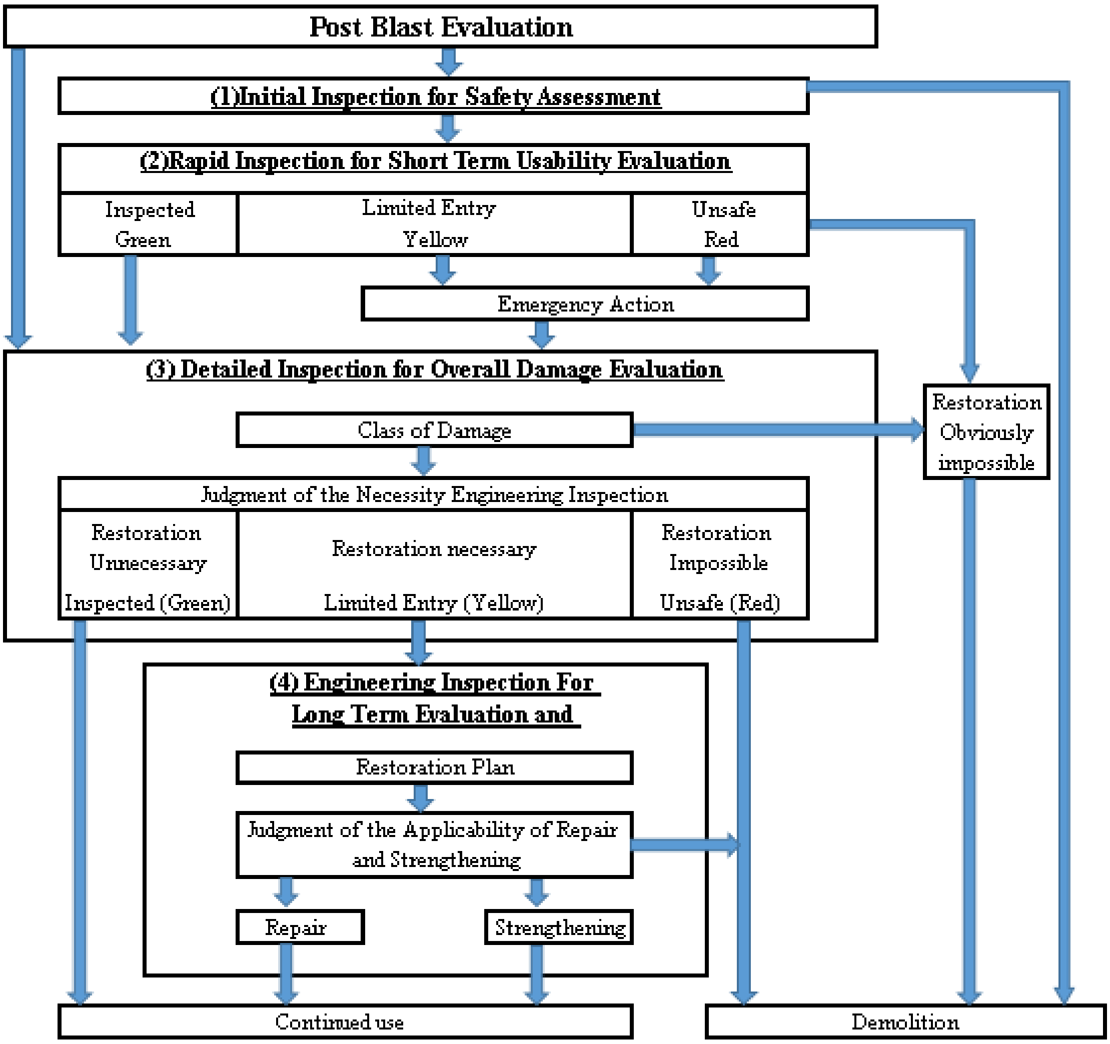

Figure 2: General Procedure of Post Blast Damage Evaluation for RC Building

3.2 Method of Post-Blast Damage Evaluation and Safety Assessment

3.2.1 Initial Inspection for Safety Assessment;

Immediately (or when it is possible) after explosion occurrence, it is very important to investigate the general damage distribution and identify the most severely damaged area where emergency rescue action is required.

This first announcement of building damage is very important to identify the imminent danger which shall be easily and visually assessed by trainee or residents through a wall around the exterior or interior of the building.

3.2.2 Rapid Inspection for Short Term Usability Evaluation

Rapid evaluation implies both temporary and emergency inspections on the assumption that there is an emergency require a number of judgments to be made by quick and visual inspection after an explosion that has damaged buildings.

The judgment is temporarily made for short term usability according to this criterion and may be changed after the damage has been surveyed later by a detailed inspection with an ample period of time for long term usability.

The purpose of the rapid evaluation of damaged buildings is to judge the risk of collapse or tip-over of the buildings damaged by an explosion or falling of building components due to aftershocks as soon as possible, and to provide information on the risk of using the buildings before they are restored for long-term use.

To inspect damaged buildings and judge the degree of danger, those who are qualified for quick inspection of damaged buildings visually inspect the appearance of buildings and their parts at the site for settlement, inclination, and destruction.

Some emergency repairs may be applied for temporary use of building.

1. Exterior and Interior Inspection: Figure 3 illustrates the flowchart showing Rapid Evaluation Inspection for RC structures.

Firstly the outside of the building is inspected in terms of building settlement, leaning, structural element damage, falling hazards, and overturning hazards.

Secondly the inside of the building is inspected in terms of structural element damage, falling hazards, and overturning hazards. If the exterior inspection rates the building Dangerous, the interior inspection is not necessarily required. Unless otherwise, the interior inspection is required.

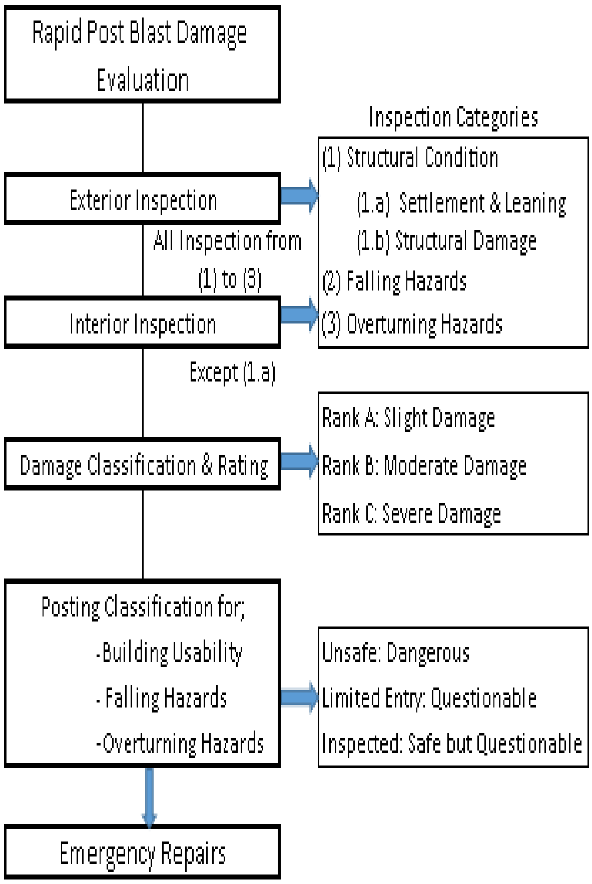

Figure 3: Rapid Evaluation for Reinforced Concrete Procedure

2. Class of Damage: Damage is rated for the three inspection categories; building settlement, leaning, and structural element damage as shown in Table 2.

Damage rating for structural elements is based on a damage ratio, defined as a ratio of the numbers of damaged structural elements and the structural elements inspected. For detailed rating of degree of damage to structural elements, refer to Table 3.

Table 2: Ranking of Building Settlement and Leaning, and Damage of Structural Elements (Rapid Evaluation)

Criteria	Settlement S (m)	Leaning Angle Θ	Structural Elements Damage
Rank A	S ≤0.2	Θ ≤1/60	E(IV)/E<10%, or E(V)/E <I%
Rank B	0.2< S ≤1.0	1/60<Θ≤ 1/30	10%≤E(IV)/E<2%, or 1%≤E (V)/E< 10%
Rank C	1.0< S	Θ>1/30	E(IV)/E ≥20%, or E (V)/E ≥10%,

Notes: **E(IV)** : The number of structural elements rated IV of damage level,
E(V) : The number of structural elements rated V of damage level,
E : The Total number of structural elements inspected.

Table 3: Rating of damage level to structural elements

Damage Level	Description of Damage
I	Visible narrow cracks on concrete surface (Crack width is less than 0.2 mm)
II	Visible clear cracks on concrete surface (Crack width is about 0.2 -1.0 mm)
III	Local crush of concrete cover
	Remarkable wide cracks (Crack width is about 1.0 - 2.0 mm)
IV	Remarkable crush of concrete with exposed reinforcing bars
	Spalling off of concrete cover (Crack width is more than 2.0 mm)
V	Buckling of reinforcing bars
	Cracks in core concrete
	Visible vertical and/or lateral deformation in columns and/or walls
	Visible settlement and/or leaning of the building

3. Building Usability and Safety Classification: using these classifications for building usability and other hazards as indicated in Tables 4, posting classification for the building can be determined as 'Unsafe' if either of the three categories rated Dangerous, 'Limited entry" if either of the three categories rated Questionable, or

"Inspected" if all of the three categories rated Safe. Table 5 shows the criteria for the posting classification**.**

Table 4: Classification of Building usability and safety for falling and overturning hazards, (Rapid Evaluation)

Classification	Building Usability	Safety for falling and overturning hazards
Dangerous	Rank C ≥ 1 or Rank B ≥ 2	
Questionable	Rank B ≥ 1 or Level of damage III or more	Rank B ≥ 1
Safe	None of the above criteria	

Table 5: Posting classification (Rapid Evaluation)

Categories / Posting Classification	Building Usability	Falling Hazards	Overturning Hazards
Unsafe (Red)	Dangerous	any	any
	Any	Dangerous	any
	Any	any	Dangerous
Limited Entry (Yellow)	Questionable	any	any
	Any	Questionable	any
	Any	any	Questionable
Inspected (Green)	Safe	Safe	Safe

4. Emergency Repairs: Emergency repairs are temporarily applied to the building classified as Dangerous (Red) or Questionable (Yellow) until the overall restoration begins. As shown in Fig. 4 prior to applying the emergency repairs, the structural elements rated III or greater in degree of damage must be inspected first, and then the appropriate repairs are applied to the vertical load system and lateral load system. Until the overall restoration is done, the building movement must be monitored continuously.

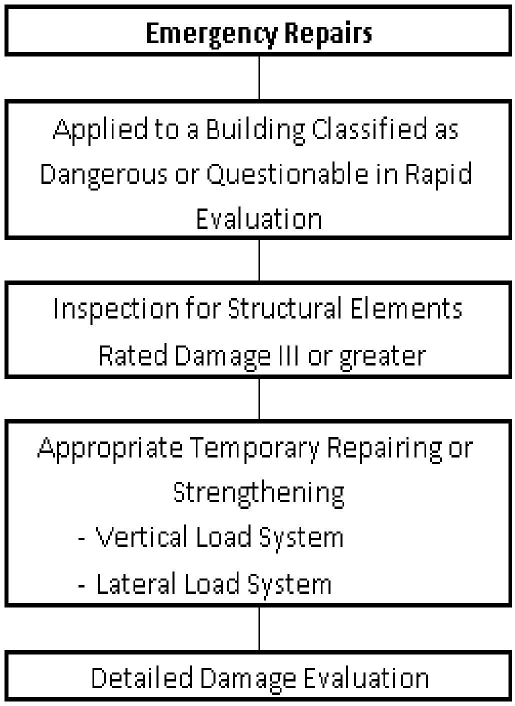

Figure 4: Flowchart of Emergency Action

3.2.3 Detailed Damage Evaluation Inspection for Safety Assessment

This method is primarily used to evaluate the buildings posted Green after the Rapid Evaluation. Normally this will be done by having engineers familiar with building design observe the damage and assess its impact on life safety.

Ideally, this evaluation will be carried out by a team of at least two structural engineers, to evaluate the overall damage classification and ranking.

1. Overall Damage Classification: Figure 5 shows the Overall Damage Classification for RC structures. The structural engineers inspect the building in terms of building settlement, leaning, and structural element damage at the most severely damaged story.

The inspection ratio, defined as a ratio of the number of structural elements inspected and the total number of the structural elements, must be more than 50% or more to make the classifications more reliable. If serious damage is found to non-structural elements such as outside stairs, and exterior finishes, as well as falling or overturning hazards, further inspection is needed.

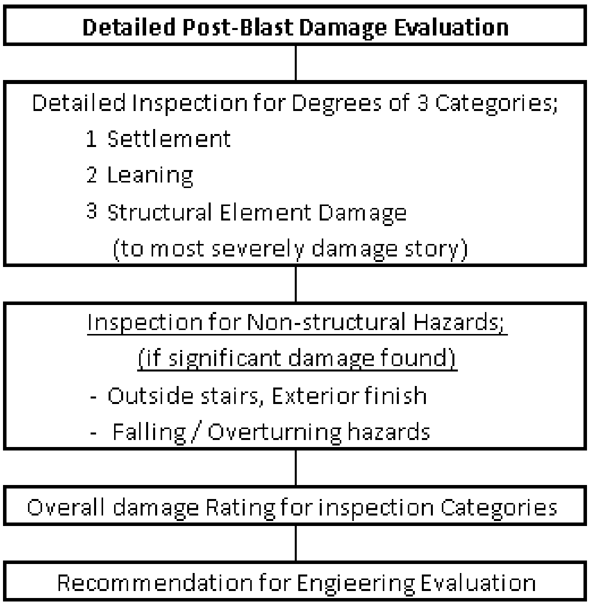

Figure 5: Flowchart of Detailed Evaluation

2. Damage Ranking: Tables 6, indicate the overall damage ratings for building settlement, leaning, and structural element damage. The building may be classified as Class 1 (slight) to Class 5 (total/collapse).

Criteria for the building leaning as shown in Table 6 are slightly different from those in Table 2. Overall structural damage is rated with respect to "Approximate Story Damage Ratio", defined by summarizing the degree of damage at a given damage level.

3. Determination of Building Damage Classification: The severest overall damage rating among the three categories is taken as the overall building damage classification. Table 7 shows the overall damage rating that can be used to take the appropriate actions and restoration to the damaged building.

3.2.4 Detailed Engineering Inspection for Long Term Usability Evaluation and Restoration

Engineering Evaluation Inspection reviews of the building design, construction, and how the building has performed in recent explosion event to understand its potential performance in future and to determine what repair or strengthening is required to bring it into a satisfactory level of compliance or to simply improve its future performance.

Rapid and Detailed Evaluation for buildings are a basic sifting method for identifying the worst of the immediate hazards. The fact that a building may have a green postcard does not mean that it has behaved satisfactorily, and nor does it mean that it will behave satisfactorily in a future event. It simply identifies that no significant damage has been found and the building may be considered as safe as it was prior to the explosion. This means it is important for the engineering community to reinforce the message that further evaluation is generally needed, even where a building has been green post carded. Engineers completing detailed evaluation must not rely unduly on the rapid and detailed evaluation, but rather must form their own views based on a fully considered evaluation. The rapid and detailed evaluation should be taken as a guide only.

Table 6: Overall building damage rating

Overall damage Rating	**Max. Settlement S(m)**	**Leaning Angle Θ**	**Structural element damage**
Class 1 (slight)			D≤5
Class 2 (small)	S≤0.2	$\Theta \leq 1/100$	5<D≤10
Class 3 (moderate)	0.2<S≤1.0	$1/100 < \Theta \leq 3/100$	10<D≤50
Class 4 (severe)	S > 1.0	$3/100 < \Theta \leq 6/100$	D>50
Class 5 (collapse)		Θ>6/100	Dv=50
D : Approximate story damage ratio (D = DI + DII + DIII + DIV + DV)			
DI - DV : degree of damage at a given damage level for Structural elements rated from I to V respectively at the most severely damaged story ; defined as			
DI =10*BI/A ≤ 5 ,			
DII = 26* BII/A ≤ 13,			
DIII= 60* BIII/A ≤ 30,			
DIV = 100*BIV/A ≤ 50, and			
DV = (1000/7) * BV/A ≤ 50.			
If BV/A > 0.5, then overall structural damage is rated Class 5, where BI - BV are the numbers of damaged elements rated from I to V respectively, and A is the number of elements available for inspection.			

Table 7: Building Damage Classification and Posting

Rating	**Posting**	**Restoration**	**Action required**
Class 1 (slight)	Green	Unnecessary	Continuous use
Classes (2~4) (small to severe)	Yellow	Necessary	Engineering Evaluation
Class 5 (collapse)	Red	Impossible	Demolition.

4 Conclusions

Following the damage due to explosion, decisions shall be taken regarding the usability, safety, emergency action and restoration plan.

Building post damage evaluation and inspection shall be applied systematically and practically in proper time and by appropriate team, as summarized in table 8, before disastrous incidents would occur.

Starting from reviewing of different existing guidelines for post-earthquake building damage evaluation, developed procedure for post-blast damage evaluation of reinforced concrete building has been proposed in this paper. .

Table 8: Post Blast Damage Inspection Methods

Method of Inspection		Purpose	Evaluation Methodology	Conducted By
1	Initial Inspection	First announcement of building damage	Reports of eye witness & Feelings by local habitants	Trainee; Emergency services, or Reconnaissance Teams
		Assess aggregate damage for affected area		
2	Rapid Inspection	For Safety Assessment and Short-Term Usability	Quick visually inspection outside/inside of the building	Engineer or Building Inspectors
		Judgment of (unsafe, Limited Entry or inspected)		
		Decision of emergency action and further inspection requirement		
3	Detailed Damage Inspection	Further to Rapid Inspection and revised building posted; (inspected and limited entry)	Detailed damages inspection and Damage Classification	Structural Engineer or Expert Inspector
		For Safety assessment and Overall damage evaluation		
		Judgment of (unsafe, Limited Entry or inspected)		
		Decision of further inspection requirement		
4	Detailed Engineering Inspection	For Restoration method and design and Long-Term Usability	Accurate determining of residual capacity	Done by expert Engineer or Consultant
			Testing (NDT and Destructive tests)	
		Judgment of (Permanent use or Demolition)	Decision of restoration methods and materials	

References

[1] Donald O. Dusenberry, Blast-Resistant Design of Building Handbook, Wiley & Sons, New Jersey, 2010.

[2] M.Y.H. Bangash, Shock,Impact and Explosion-Structural Analysis and Design, Springler, Germany, 2009.

[3] Mays, G. C.; Smith, P. D; Blast Effects on Buildings, Design of Buildings to Optimize Resistance to Blast Loading, Tomas Telford, 2003.

[4] Jayasooriya, Ruwan and Thambiratnam, David and Perera, Nimal and Kosse, Damage assessment of 3D reinforced concrete frame under external explosion loading. In: Int. Con. On Civil Eng., 9-10 Mar. 2010.

[5] Norazman M Nor, M. Zainuddin Musa, Neza Ismail, M. Alias Yusof and Hapsa Husen, Damage Evaluation Procedure for Building Subjected to Blast Impact, Eur. Jour. of Scientific Research, ISSN 1450-216X Vol.39 No.3, pp.326-335, 2010.

[6] Tezeswi Phanirama Tadepalli, Performance Evaluation of Low-Rise Concrete Frame Building Structures in Moderate Seismic Zones Subject to External Blast Loading, The University of Mississippi, PhD, Aug.2010.

[7] Edward Eskew and Shinae Jang, Impacts and Analysis for Buildings under Terrorist Attacks, University of Connecticut, Literature Survey Report, Nov. 2012.

[8] Mohammed S. Al-Ansari, Building Response To Blast and Earthquake Loading, International Journal of Civil Engineering and Technology, ISSN 0976-6316, Vol.3, Issue 2 , pp.327-346, 2012.

[9] A. J. Kappos, Dynamic Loading and Design of Structure, Spon Press, 2004.

[10] Technological Council, ATC 20 Procedures for post-earthquake safety evaluations of buildings 1989. ATC 20–1 Field Manual for post-earthquake safety evaluations of buildings 1989. ATC 20-2 Addendum to ATC 20 post-earthquake building safety evaluation procedures 1995.

[11] Johanny M. Hernandez Morales and Shunsuke SUGANO, Improvement of Dominican Guideline for Post-Earthquake Evaluation of Building, Synopses of Master Papers, Bulletin of IISEE, 47, 67-72, 2013.

[12] Watabe, M., Yamanobe, K. 1994. The criteria for assessment of seismically damaged degree of buildings in Japan. Cheng &Wang (ed.), Post-Earthquake Rehabilitation and Reconstruction; Proc., Sym., 251-264, 1996.

[13] Emil-Sever GEORGESCU, Liviu CRAINIC, Radu VACAREANU, Basarab CHESCA, Cristian BALAN, Cristian Paul STAMATIADE, Gabriela IONESCU, A Methodology for Post-Earthquake Damage Investigation and Safety Assessment of Buildings in Romania, In Euro- Mediterranean and Worldwide Context , The 14 The World Con. on Earthquake Eng., Beijing, China, Oct. 12-17, 2008.

[14] New Zealand Society for Earthquake Engineering Inc., Post Earthquake Building safety Evaluation Procedures, preparedness Checklist and Response Plan for Territorial Authorities, 1998.

[15] Yoshiaki Nakano, Masaki Maeda, Hiroshi Kuramoto, and Masaya Murakami, Guideline for Post–Earthquake Damage Evaluation and Rehabilitation of RC Buildings in Japan, 13th World Con. on Earthquake Eng., Vancouver, B.C., Canada, August 1-6, 2004.

[16] Taiki SAITO and Sunil Kumar THAKUR, POST-EARTHQUAKE QUICK RISK INSPECTION SYSTEM FOR BUILDINGS, Int. Sym. on Disasters Management, in Saudi Arabia (Riyadh) 14-17/10/1430.