ARTICLE IN PRESS

HBRC Journal (2016) **xxx**, xxx–xxx

Housing and Building National Research Center

HBRC Journal

http://ees.elsevier.com/hbrcj

Seismic vulnerability evaluation of existing R.C. buildings

Sameh A. El-Betar

Housing & Building National Research Center, Egypt

Received 19 May 2016; revised 22 August 2016; accepted 25 September 2016

KEYWORDS

Seismic;
Vulnerability;
Evaluation;
Existing;
R.C. buildings

Abstract Earthquakes are natural phenomena that occur at several places of the world. Severe earthquakes, when near inhabited districts, have caused extensive loss of life and property. Although some progress in the area of seismic prediction has been made, earthquakes cannot be accurately predicted in time, magnitude or location. Therefore, the main way of decreasing losses is to construct seismic resisting structures. Recent earthquakes illustrate that the older buildings, which are not designed to resist earthquakes, have been damaged rather than the buildings which have been designed according to seismic codes. Many existing buildings in Egypt were designed to resist the gravity loads only (GLD) without seismic provisions. The need is raised to study the vulnerability of these buildings to avoid a serious risk. In this paper, the light is shed on the significant contributions in the field of seismic vulnerability evaluation of buildings in order to suggest a suitable procedure for seismic evaluation of existing R.C. buildings in Egypt. Seismic evaluation was applied on the selected two case studies, one represents the GLD buildings and the other represents the buildings designed according to Egyptian code. Moreover, pushover analysis was conducted to investigate the vulnerability of these buildings.

Introduction

Seismic vulnerability evaluation is defined as an approved process or methodology of evaluating deficiencies in a building that prevents the building from achieving a selected performance objective. The seismic vulnerability evaluation of the existing buildings is required for the following: buildings may not have been designed to resist seismic forces or designed before the publication of the current seismic codes, the condition of buildings is apparently of poor quality or deteriorated with time and change of use of the building and the soil has a high liquefaction potential. Depending on the seismic evaluation, a building can be demolished, retrofitted to increase its capacity, or modified to decrease its seismic demand [1,2].

The earthquake risk at any location depends on the seismic hazard as well as the vulnerability of its structures. The seismic hazard evaluation considers the likelihood of earthquake of a particular magnitude or intensity affecting a site. The "risk"

E-mail address: Elbetar2016@gmail.com

Peer review under responsibility of Housing and Building National Research Center.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.hbrcj.2016.09.002

Please cite this article in press as: S.A. El-Betar, Seismic vulnerability evaluation of existing R.C. buildings, HBRC Journal (2016), http://dx.doi.org/10.1016/j.hbrcj.2016.09.002

means expected loss (such as lives, injury, property damage) due to a particular hazard for a given area and reference period. Based on mathematical calculations, risk is the product of hazard and vulnerability [3]. The seismic vulnerability of a structure can be described as its susceptibility to damage by ground shaking, and this includes foundations, columns, beams, and floor slabs [2].

The seismic vulnerability evaluation is a complex process, which has considered design of building as well as deterioration of the material and damage caused to the building [1]. The vulnerability of a building subjected to an earthquake is depended on seismic deficiency of that building. The seismic deficiency is defined as a condition that will prevent a building from meeting the required performance objective. Thus, a building evaluated to provide full occupancy immediately after an event may have significantly more deficiencies than the same building evaluated to life safety. Life Safety performance level means the damage to the structure has occurred (after earthquake) but some margin against either partial or total structural collapse remains, while, immediate occupancy performance means very limited damage to both structural and nonstructural components.

The most categories of seismic deficiencies are as follows: 1 – Discontinuity in the load path which transferred the inertial forces from the mass to the foundation; 2 – Low strength for the lateral load system elements such as weak stories; 3 – Low stiffness of lateral loads system elements such as soft story condition; 4 – Low ductility of lateral load system elements; 5 – Lack of Redundancy, Redundancy means providing multiple continuous load paths in the structural system; 6 – Configuration Irregularities: The vertical irregularities that may affect the seismic performance are stiffness Irregularity, weight (Mass) irregularity, vertical geometric irregularity such as setbacks and vertical discontinuity in load path or the lateral force-resisting elements. The horizontal irregularities that may affect the seismic performance are torsional Irregularity, reentrant corner irregularity and diaphragm discontinuity irregularity; 7 – Deterioration of structural materials; 8 – The pounding action which occurs when the gap between buildings is insufficient; and 9 – Foundation deficiencies [4].

The seismic vulnerability evaluation of existing buildings is performed either qualitatively or quantitatively: quantitative evaluation depends on the judgment of experienced well trained engineers with the aid of some empirical guides. Analytical evaluation is performed through one or more of the different approaches used for seismic design or analysis of structures. The evaluation method is chosen according to the purpose of the evaluation as well as the importance of the evaluated structure [5].

The current approaches in seismic vulnerability evaluation methods were divided into three main groups depending on their level of complexity. The first, most simple level is known as "Walk Down Evaluation" or rapid evaluation such as FEMA 154 procedure. Evaluation in this first level does not require any analysis and its goal is to determine the priority levels of buildings that require immediate intervention. Preliminary assessment methodology is applied when more in-depth evaluation of building stocks is required. These analyses require data on the dimensions of the structural and nonstructural elements in the most critical story. The procedures in third tier employ linear or nonlinear analyses of the building under consideration and require the as-built dimensions and the reinforcement details of all structural elements [6]. Rapid screening evaluations are suitable for earthquake scenario projects where a large number of buildings have to be evaluated. While, analytical methods for the assessment of the vulnerability of buildings take even more time and serve, it can be used for the evaluation of individual buildings only, possibly as a further step after the rapid screening of potential hazardous buildings in a multi-phase procedure [3].

The common method for rapid evaluation is FEMA 154 [7]. The purpose of FEMA 154 is to provide a methodology to evaluate the seismic safety of a large inventory of buildings quickly and inexpensively, with minimum access to the buildings, and determine those buildings that require a more detailed examination. FEMA 154 has been updated based on the experience from the widespread use of the methodology and the new knowledge about the performance of buildings during damaging earthquakes. The third edition of FEMA 154 is now referred to as FEMA P-154 [8]. For detailed evaluation, Durgesh [9] indicates that FEMA 310 [10] is more suitable for use in buildings of developing countries. FEMA 310 was updated to seismic evaluation of existing buildings (ASEC 31-03) [11] which has become a national standard for seismic evaluation. Recently, ASCE 31-03 merges with seismic rehabilitation of existing buildings (ASCE 41-06) into a common document which is called seismic evaluation and retrofit of existing buildings procedure (ASCE/SEI 41-13) [1].

Seismic evaluation of R.C. buildings in Egypt

Existing buildings need seismic evaluation because our understanding the effect of earthquakes has improved after buildings were constructed. Egypt is considered a region of moderate seismicity but a large number of existing buildings in Egypt, which have inadequate seismic resistance, may create a serious risk. Fig. 1 shows the flowchart of the proposed seismic evaluation of existing buildings in Egypt. The evaluation begins with a rapid evaluation procedure, which is based on FEMA P-154 procedure to suit the Egyptian conditions. It can be used as a method for statistical identification buildings where a large number of buildings have to be evaluated.

The rapid procedure utilizes a scoring system. Buildings may be reviewed from the sidewalk without the benefit of building entry, structural drawings, or structural calculations. Results were recorded on the Data Collection Forms. There are five Data Collection Forms, one for each of the following five regions of seismicity: Low, Moderate, Moderately High, High, and Very High. Each Data Collection Form has a Level 1 page and an optional Level 2 page. Level 2 screening is more detailed than Level 1 screening. It is designed to apply more specific modifiers for vertical and plan irregularities, pounding, and existing retrofits. For less significant conditions, only a portion of Level 1 score modifier is used.

The Data Collection Form includes space for documenting building identification information, including its use and size, a photograph of the building, sketches, and documentation of pertinent data related to seismic performance. The structural scoring system consists of a matrix of basic structural hazard scores (one for each building type and its associated seismic lateral-force-resisting system). The Score modifiers are related to observed performance attributes and are then added (or subtracted) to the Basic Score to arrive at a Final Score. Final

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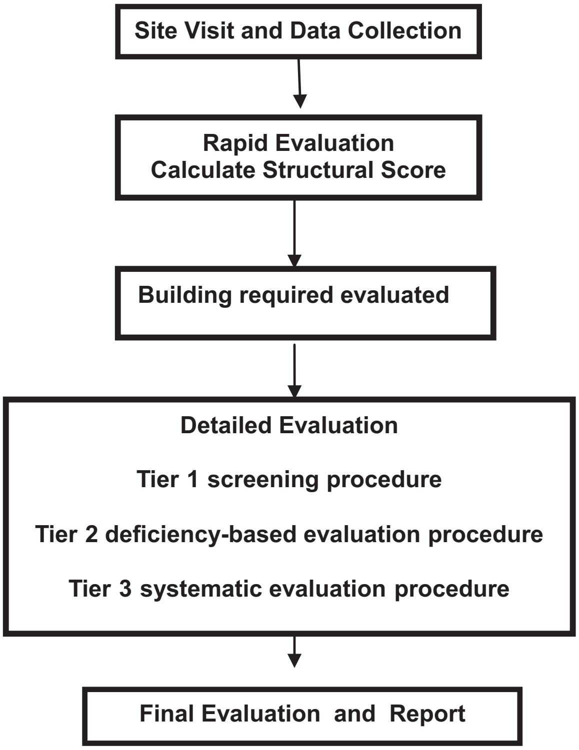

Fig. 1 Evaluation procedure.

Scores typically range from 0 to 7, with higher scores corresponding to better expected seismic performance and a lower potential for collapse. Buildings with final score of 2 or less should be investigated in the detailed evaluation.

For buildings that did not achieve the seismic resistance in rapid visual inspection, as well as individual structure that required evaluated, the multi-phase procedure of ASCE/SEI 41-13 is used. The seismic evaluation ASCE/SEI 41-13 includes three tiers of evaluation. Tier 1, screening procedure, requirements tend to be general and conservative in nature, Tier 2, deficiency-based evaluation procedure, is more detailed, and Tier 3, systematic evaluation procedure, is specific and involved. The design professional may choose to (1) report deficiencies and recommend mitigation or (2) conduct further evaluation, after any tier of the evaluation process.

Tier 1 consists of several sets of checklists that allow a rapid evaluation of the structural, nonstructural, and foundation and geologic hazard elements of the building. If deficiencies are identified for a building using the checklists, the design professional may proceed to Tier 2. In Tier 2 procedure, an analysis of the building that addresses all of the potential deficiencies identified in Tier 1 screening shall be performed. Analysis in Tier 2 is limited to simplified linear analysis methods. Limitations on the use of the Tier 1 and Tier 2 procedures of R.C. frames are as follows: 12 stories for moderate seismicity and 8 stories for high seismicity. In Tier 3, the complete analysis of the response of the building to seismic hazards is performed, implicitly or explicitly recognizing nonlinear response. Force levels used for Tiers 2 and 3 analyses for evaluation of existing buildings are reduced from the conservative level used in design for new buildings by multiplying a factor of 0.75. This reduced force level is justified because (a) the actual strength of the components will be greater than that used in the evaluation and (b) an existing building does not need to have the same level of factor of safety as a new building since the remaining useful life of an existing building may be less than that of a new building [1].

Case studies

The most common type of existing buildings in Egypt is the reinforced concrete framed buildings. Many of these buildings were designed to resist gravity loads only. Gravity load designed educational buildings had been heavily damaged by the earthquake in October, 1992, in Egypt in the regions near the epicenter. Fig. 2 illustrates the typical damage in some reinforced concrete school buildings at Fayoum, Egypt.

Most of the victims were school students because there was no previous knowledge of the ideal behavior dealing with earthquakes, the case that leads to the students' rushing into corridors and stairs. As a result of the weakness of some parapets of corridors, some students fell into the playground. Moreover, the existence of only one stair at most schools causes the accumulation of students over the stair, which led to the death of some students.

The seismic deficiencies of these buildings are concentrated in the following: (1) Low transverse reinforcement in the columns and the absence of shear reinforcement in beam-column joints; (2) The beam bottom reinforcement is terminated within the beam-column joints with a short embedment length; (3) The columns of school model, in the long direction, have bending moment capacities less than those of the joining beams; and (4) Sometimes poor execution of concrete [12].

Two case studies were selected for applying the seismic evaluation procedure. The case study 1 model is a sample of old school buildings in Egypt, which was designed and constructed for three decades before 1992 earthquake, as shown in Fig. 3. Typical floor height of the model is 3.3 m and the ground floor from the foundation level is 4.5 m. The model is fully designed for gravity loads to represent the GLD buildings. The lateral load resisting system in both directions consists of non-ductile reinforced concrete frames. The building has filler hollow brick walls with large opening so the infill walls are neglected. The cross sections of exterior and interior columns are 250 × 500 mm and 250 × 600 mm. The cross sections of beams are 120 × 620 mm for B1, 120 × 920 mm for B2 and 250 × 720 mm for B3.

The second case study represents the school buildings which were constructed in Egypt after 1990, as shown in Fig. 4. The building consists of columns and beams monolithically cast with solid slabs. Typical floor height is 3.45 m while the ground floor height is 4.5 m. The building is designed according to the Egyptian code. The cross sections of exterior and interior columns are 300 × 700 mm and 300 × 800 mm. The cross section of beams is 250 × 700 mm. The columns and beams have the same cross sections throughout the height of the frames, and the columns are considered fixed at the base.

Rapid evaluation

The lateral load system of case studies is moment resisting frame. The case studies do not include vertical and plan irregularities or pounding. Therefore, only Level 1 in FEMA P-154

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Fig. 2 School buildings at Fayoum, Egypt, after 1992 earthquake [12].

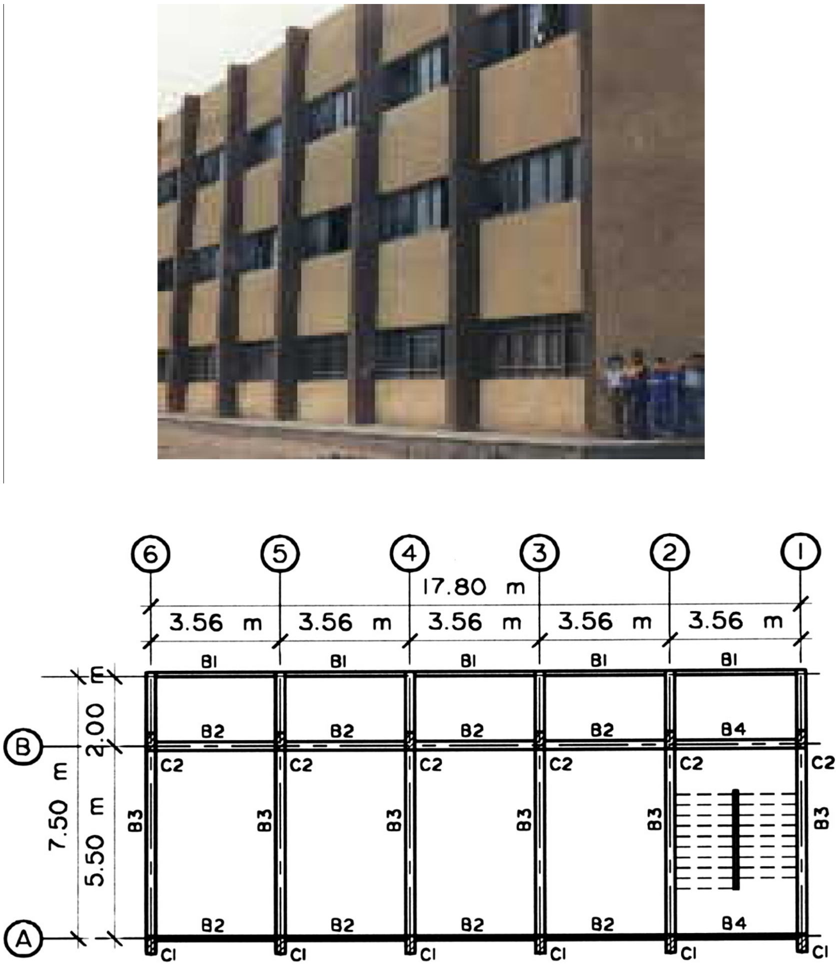

Fig. 3 Details of case study 1 (an old school building in Egypt).

score modifier is used. The case studies are assumed to be located in moderate seismicity region and the type of soil is dense. Fig. A1 shows the selected Data Collection Form. Table 1 illustrates the final structural score for case studies which equals to the basic score plus score modifiers. For case study 1, the total score (S) equals to 1.8 (2.1–0.3 (pre-code)) which is less than 2; therefore, the building has needed a detailed evaluation. On the other hand, the total score of the case study 2 equals to 4.1 (2.1 + 2 (after code)) which is greater than 2.

Detailed evaluation

Tier 1 is the first phase in the detailed evaluation (ASCE/SEI 41-13). The purpose of the preliminary evaluation is to identify the area of seismic deficiencies in the

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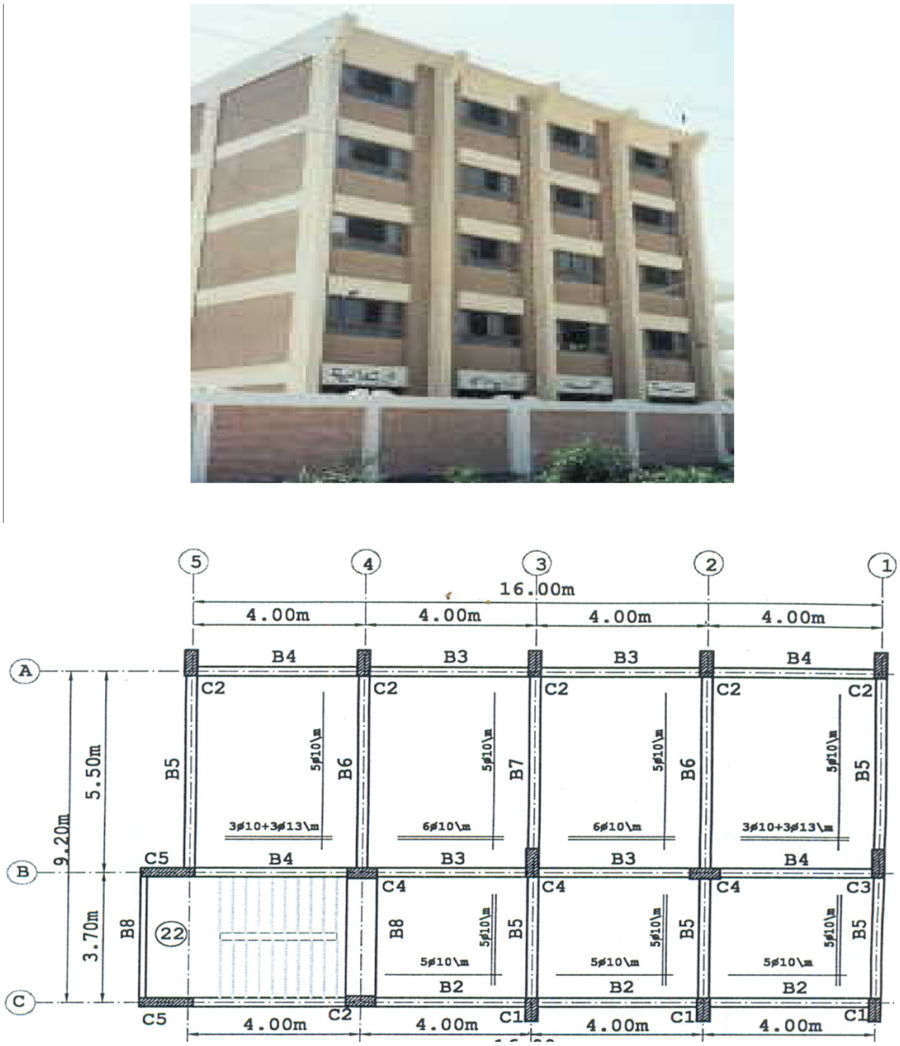

Fig. 4 Details of case study 2 (a new school building in Egypt).

Table 1 Determination the final score (level 1) from data collection form.

	Case 1 (old school, C1)	Case 2 (new school, C1)
Basic score	**2.1**	**2.1**
Severe vertical irregularity	−1.1	−1.1
Moderate Vertical irregularity	−0.7	−0.7
Plan irregularity	−0.8	−0.8
Pre-code	**−0.3**	−0.3
After code	2	**2**
Hard rock soil	1.1	1.1
Soft soil (1–3 stories)	−0.7	−0.7
Soft soil (> 3 stories)	−0.8	−0.8
Minimum score	0.3	0.3
Final score	**1.8**	**4.1**
Comment	Required detailed evaluation	

C1 moment resisting frame.

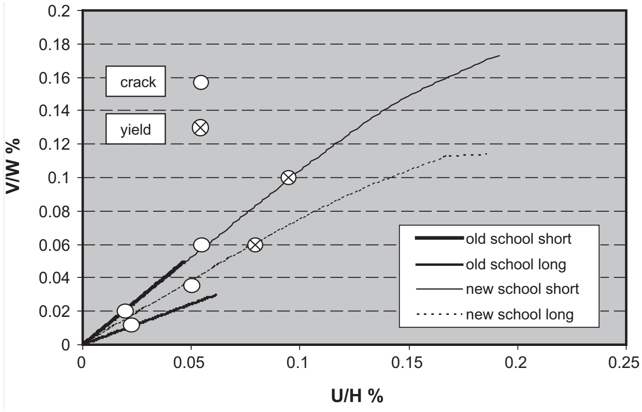

Fig. 5 Capacity curves of case studies.

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buildings. It is necessary to collect relevant data of a building as much as possible through drawings, enquiry, design calculations, soil report (if available), inspection reports, reports of previous investigation, and previous repair works [2]. At least one site visit shall be made to observe exposed conditions of building configuration, building components, site and foundation, and adjacent structures [1]. The most important step for proper condition assessment of a building is the identification of any existing damage and the possible causes of the damage.

Checklists required for Tier 1 screening for life safety performance consist of very low, low, moderate and high seismicity. Table A1 shows the checklists required for the moment resisting frame in moderate seismicity. In the case of the building in high seismicity, it is required to complete the items for low and moderate seismicity, in addition to the items of high seismicity such as strong column-weak beam, column and beam bar splices and stirrup spacing. Each of the evaluation statements in this checklist shall be marked Compliant (C), Noncompliant (NC), Unknown (U), or Not Applicable (N/A).

Tier 1 screening has been applied on the case study 1, and the checks of axial and shear stresses of columns are carried out. The typical model of old school building passes all items in Tier 1 procedure. But, it does not meet the some items of life safety performance objective. It has been found several deficiencies in the model. The deficiencies are as follows: the lack of redundancy in the short direction, one bay moment frame in the short direction (less than 2). The second deficiency is the high value of height-to-thickness of parapets of corridor (above than 2.5). The design professional may choose to (1) report deficiencies and recommend mitigation or (2) conduct to inter in the second phase (Tier 2). For Tier 2, the analysis of deficiency shall be performed based on the requirements of evaluation identified in Tier 1. In this case, the building analysis requires the as-built dimensions, the reinforcement details of all structural elements, soil report and core tests to determine the strength of concrete. On the other hand, the school buildings constructed after 1990 do not include these deficiencies. The number of bays of frames is greater than 2, and the material of parapets of corridor is reinforced concrete.

Pushover analysis

The pushover analysis is conducted to create the capacity curve of case studies when subjected to lateral forces. It is generated by subjecting a detailed structural model to one or more lateral load patterns (vectors) and then increasing the magnitude of the total load in a step-by-step and the corresponding incremental displacement is calculated to generate a nonlinear inelastic force-deformation relationship for the structure at a global level. The results from pushover analyses are presented in graphs that describe the variation of base shear versus top displacement. Pushover technique allows the sequence of cracking, yielding and failure on the members and structure and it is benefit to highlight potential weak regions in the structure.

The pushover analysis was conducted by using a Computer Program for Inelastic Damage Analysis of R.C. Structures (IDARC version 6) [13]. The building is modeled as a series of plane frames linked by a rigid horizontal diaphragm. Each frame is in the same vertical plane, and no torsional effects are considered. The program uses a distributed flexibility model in constructing the element stiffness matrix leading to include the effect of spread plasticity. Column elements are modeled considering macro-models with inelastic flexural deformations, and elastic shear and axial deformations. Beam elements are modeled using a nonlinear flexural stiffness model with linear elastic shear deformations considered.

Fig. 5 shows the overall capacity curves for case studies as well as the sequence of component cracking, yielding and failure for R.C. elements. Pushover analysis results show that the response of old school model is mainly elastic with very small base shear. Significant structural damage is anticipated in R.C. elements when the base shear reaches 0.01–0.02 W, where W is the total weight. The maximum values of lateral load related to the total weight (V/W) are equal to 0.05 and 0.03 for short and long directions which are low values, especially in long direction. Therefore, the vulnerability of existing GLD school buildings may occur at high expected ground accelerations. For new school building model, the pushover analysis illustrates that the cracks in R.C. elements are anticipated when the base shear exceeds 0.04–0.06 W, and the yield in R.C. elements occurs at 0.06–0.1 W. The ultimate lateral loads are equal to 0.173 W and 0.12 W for short and long directions. It is concluded that the school buildings designed according to Egyptian code have a high capacity to resist earthquakes. Moreover, the values of ultimate lateral loads for new school building are 3.5–4 times greater than those of old school building.

Conclusions

1. To evaluate the existing R.C. buildings in Egypt, rapid screening based on FEMA P-154 procedure can be used for a large number of R.C. buildings. ASCE 41-13 methodology can be used for buildings that did not achieve the seismic resistance in rapid visual inspection, as well as individual structure that required evaluated. The priority of evaluation is for the old or non-engineered buildings in high seismic regions.
2. The GLD school buildings tend to be more vulnerable under high seismic loads, while school buildings designed according to Egyptian code have a high capacity to resist earthquakes.

Conflict of interest

The authors declare that there are no conflict of interests.

Appendix A

See Table A1 and Fig. A1.

Table A1 Tier 1 checklist.

Life safety basic configuration checklist and structural checklist for concrete moment frames	
Basic checklist	
Very low seismicity	
Structural components	
Load path: The structure shall contain a complete, well-defined load path, that serves to transfer the inertial forces associated with the mass of all elements of the building to the foundation	C
Wall anchorage: Exterior concrete or masonry walls that are dependent on the diaphragm for lateral support are anchored for out-of-plane forces at each diaphragm level with steel anchors, reinforcing dowels, or straps that are developed into the diaphragm	N/A
Low seismicity	
Building system	
General	
Adjacent buildings: The clear distance between the building being evaluated and any adjacent building is greater than 4% of the height of the shorter building	N/A
Mezzanines: Interior mezzanine levels are braced independently from the main structure	N/A
Building configuration	
Weak story: The sum of the shear strengths of the seismic-force-resisting system in any story in each direction is not less than 80% of the strength in the adjacent story above	C
soft story: The stiffness of the seismic-force-resisting system in any story is not less than 70% of the seismic-force-resisting system stiffness in an adjacent story above or less than 80% of the average seismic-force-resisting system stiffness of the three stories above	C
Vertical irregularities: All vertical elements in the seismic-force-resisting system are continuous to the foundation	C
Geometry: There are no changes in the net horizontal dimension of the seismic-force-resisting system of more than 30% in a story relative to adjacent stories	C
Mass: There is no change in effective mass more than 50% from one story to the next. Light roofs, penthouses, and mezzanines need not be considered	C
Torsion: The estimated distance between the story center of mass and the story center of rigidity is less than 20% of the building width in either plan dimension	C
Seismic-force-resisting system	
Redundancy: The number of lines of moment frames in each principal direction is greater than or equal to 2. The number of bays of moment frames in each line is greater than or equal to 2	NC
Column axial stress check: The axial stress caused by unfactored gravity loads in columns subjected to overturning forces because of seismic demands is less than 0.20 fc′. Alternatively, the axial stress caused by overturning forces alone, calculated using the Quick Check is less than 0.30 fc′ $p_{ot} = \frac{1}{M_s}\left(\frac{2}{3}\right)\left(\frac{Vh_n}{Ln_f}\right)\left(\frac{1}{A_{col}}\right)$ where h_n = Total height of building (ft), L = Total length of frame (ft), n_f = Total number of frames in the direction of loading, A_{col} = Area of the end column of the frame, V = Lateral seismic force M_s = 2 for life safety performance level	C
Connections	
Concrete columns: All concrete columns are doweled into the foundation with a minimum of 4 bars	C
Moderate seismicity:	
Complete the Following Items in Addition to the Items for Low Seismicity	
Geologic site hazards	
Liquefaction: Liquefaction-susceptible, saturated, loose granular soils shall not exist in the foundation soils at depths within 50 ft under the building	N/A
Slope failure: The building site is sufficiently remote from potential earthquake-induced slope failures	N/A
Surface fault rupture: Surface fault rupture and surface displacement at the building site are not anticipated	N/A
Seismic-Force-Resisting System	
Interfering walls: All concrete and masonry infill walls placed in moment frames are isolated from structural elements	N/A
Column shear stress check: The shear stress in the concrete columns, calculated using the Quick Check procedure is less than the greater of 100 lb/in.^{2} or 2 (fc′)0.5 $v_j^{avg} = \frac{1}{M}\left(\frac{n_c}{n_c - n_f}\right)\left(\frac{V_j}{A_c}\right)$ Where: n_c = Total number of columns, n_f = Total number of frames in the direction of loading, A_c = Summation of the cross-sectional area of all columns in the story under consideration, v_j = story shear, M_s = 2 for life safety performance level	C
Flat slab frames: The seismic-force-resisting system is not a frame consisting of columns and a flat slab or plate without beams.	N/A
Nonstructural checklist	
Partitions	
Unreinforced masonry: Unreinforced masonry or hollow-clay tile partitions are braced at a spacing of at most 10 ft in Low or Moderate Seismicity	C
URM parapets or cornices: Laterally unsupported unreinforced masonry parapets or cornices have height-to-thickness ratios not greater than 2.5 in Low or Moderate Seismicity	NC

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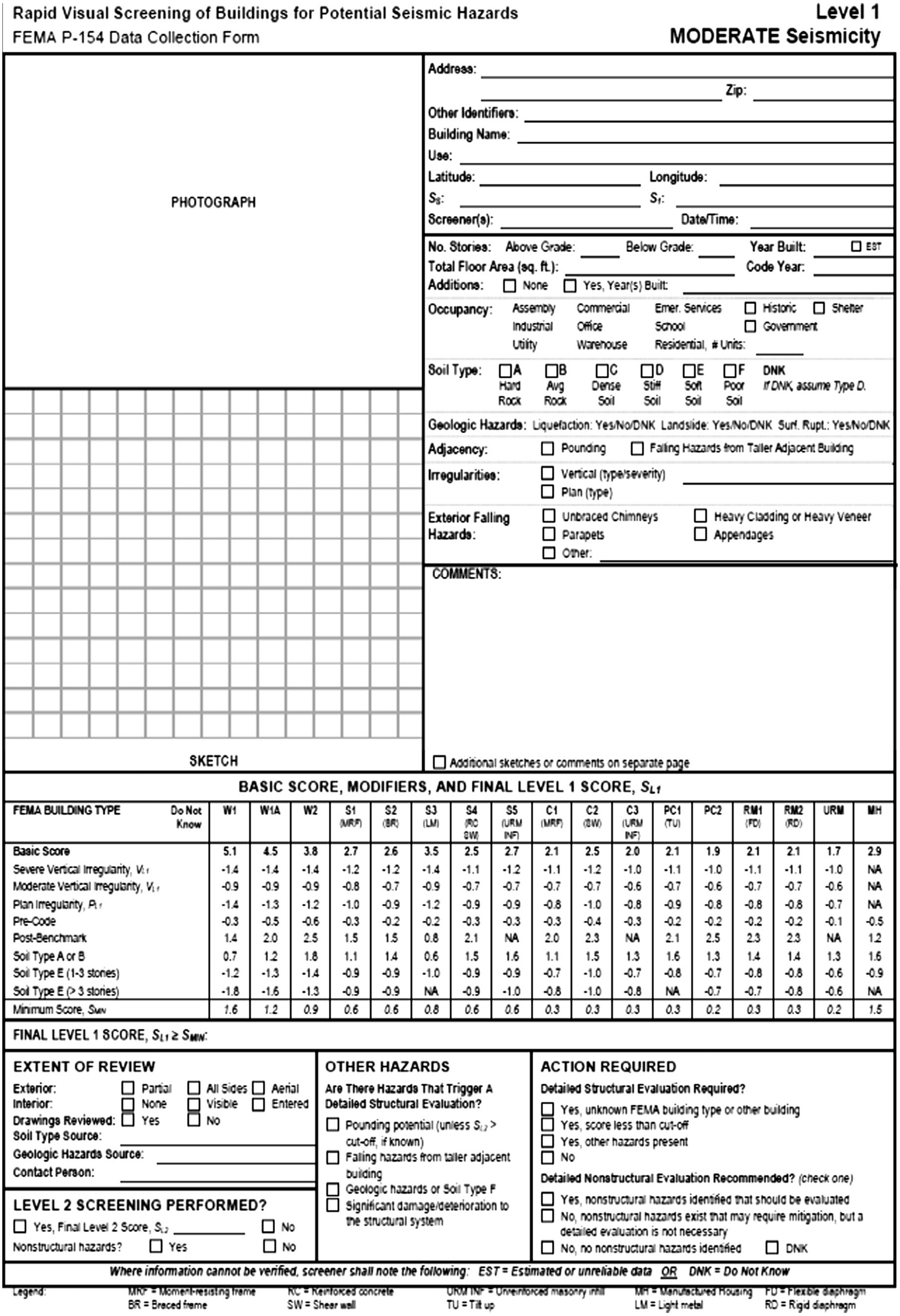

Rapid Visual Screening of Buildings for Potential Seismic Hazards
FEMA P-154 Data Collection Form

Level 1
MODERATE Seismicity

PHOTOGRAPH

Address:
Zip:
Other Identifiers:
Building Name:
Use:
Latitude: **Longitude:**
S_S: **S_1:**
Screener(s): **Date/Time:**

No. Stories: Above Grade: Below Grade: **Year Built:** ☐ EST
Total Floor Area (sq. ft.): **Code Year:**
Additions: ☐ None ☐ Yes, Year(s) Built:

Occupancy: Assembly Commercial Emer. Services ☐ Historic ☐ Shelter
Industrial Office School ☐ Government
Utility Warehouse Residential, # Units:

Soil Type: ☐A Hard Rock ☐B Avg Rock ☐C Dense Soil ☐D Stiff Soil ☐E Soft Soil ☐F Poor Soil DNK *If DNK, assume Type D.*

Geologic Hazards: Liquefaction: Yes/No/DNK Landslide: Yes/No/DNK Surf. Rupt.: Yes/No/DNK

Adjacency: ☐ Pounding ☐ Falling Hazards from Taller Adjacent Building

Irregularities: ☐ Vertical (type/severity)
☐ Plan (type)

Exterior Falling Hazards: ☐ Unbraced Chimneys ☐ Heavy Cladding or Heavy Veneer
☐ Parapets ☐ Appendages
☐ Other:

COMMENTS:

SKETCH

☐ Additional sketches or comments on separate page

BASIC SCORE, MODIFIERS, AND FINAL LEVEL 1 SCORE, S_{L1}

FEMA BUILDING TYPE	Do Not Know	W1	W1A	W2	S1 (MRF)	S2 (BR)	S3 (LM)	S4 (RC SW)	S5 (URM INF)	C1 (MRF)	C2 (SW)	C3 (URM INF)	PC1 (TU)	PC2	RM1 (FD)	RM2 (RD)	URM	MH
Basic Score		**5.1**	**4.5**	**3.8**	**2.7**	**2.6**	**3.5**	**2.5**	**2.7**	**2.1**	**2.5**	**2.0**	**2.1**	**1.9**	**2.1**	**2.1**	**1.7**	**2.9**
Severe Vertical Irregularity, V_{L1}		-1.4	-1.4	-1.4	-1.2	-1.2	-1.4	-1.1	-1.2	-1.1	-1.2	-1.0	-1.1	-1.0	-1.1	-1.1	-1.0	NA
Moderate Vertical Irregularity, V_{L1}		-0.9	-0.9	-0.9	-0.8	-0.7	-0.9	-0.7	-0.7	-0.7	-0.7	-0.6	-0.7	-0.6	-0.7	-0.7	-0.6	NA
Plan Irregularity, P_{L1}		-1.4	-1.3	-1.2	-1.0	-0.9	-1.2	-0.9	-0.9	-0.8	-1.0	-0.8	-0.9	-0.8	-0.8	-0.8	-0.7	NA
Pre-Code		-0.3	-0.5	-0.6	-0.3	-0.2	-0.2	-0.3	-0.3	-0.3	-0.4	-0.3	-0.2	-0.2	-0.2	-0.2	-0.1	-0.5
Post-Benchmark		1.4	2.0	2.5	1.5	1.5	0.8	2.1	NA	2.0	2.3	NA	2.1	2.5	2.3	2.3	NA	1.2
Soil Type A or B		0.7	1.2	1.8	1.1	1.4	0.6	1.5	1.6	1.1	1.5	1.3	1.6	1.3	1.4	1.4	1.3	1.6
Soil Type E (1-3 stories)		-1.2	-1.3	-1.4	-0.9	-0.9	-1.0	-0.9	-0.9	-0.7	-1.0	-0.7	-0.8	-0.7	-0.8	-0.8	-0.6	-0.9
Soil Type E (> 3 stories)		-1.8	-1.6	-1.3	-0.9	-0.9	NA	-0.9	-1.0	-0.8	-1.0	-0.8	NA	-0.7	-0.7	-0.8	-0.6	NA
Minimum Score, S_{MIN}		*1.6*	*1.2*	*0.9*	*0.6*	*0.6*	*0.8*	*0.6*	*0.6*	*0.3*	*0.3*	*0.3*	*0.3*	*0.2*	*0.3*	*0.3*	*0.2*	*1.5*

FINAL LEVEL 1 SCORE, $S_{L1} \geq S_{MIN}$:

EXTENT OF REVIEW

Exterior: ☐ Partial ☐ All Sides ☐ Aerial
Interior: ☐ None ☐ Visible ☐ Entered
Drawings Reviewed: ☐ Yes ☐ No
Soil Type Source:
Geologic Hazards Source:
Contact Person:

LEVEL 2 SCREENING PERFORMED?

☐ Yes, Final Level 2 Score, S_{L2} ☐ No
Nonstructural hazards? ☐ Yes ☐ No

OTHER HAZARDS

Are There Hazards That Trigger A Detailed Structural Evaluation?

☐ Pounding potential (unless S_{L2} > cut-off, if known)
☐ Falling hazards from taller adjacent building
☐ Geologic hazards or Soil Type F
☐ Significant damage/deterioration to the structural system

ACTION REQUIRED

Detailed Structural Evaluation Required?

☐ Yes, unknown FEMA building type or other building
☐ Yes, score less than cut-off
☐ Yes, other hazards present
☐ No

Detailed Nonstructural Evaluation Recommended? *(check one)*

☐ Yes, nonstructural hazards identified that should be evaluated
☐ No, nonstructural hazards exist that may require mitigation, but a detailed evaluation is not necessary
☐ No, no nonstructural hazards identified ☐ DNK

Where information cannot be verified, screener shall note the following: EST = Estimated or unreliable data OR DNK = Do Not Know

Legend:
MRF = Moment-resisting frame
BR = Braced frame
RC = Reinforced concrete
SW = Shear wall
URM INF = Unreinforced masonry infill
TU = Tilt up
MH = Manufactured Housing
LM = Light metal
FD = Flexible diaphragm
RD = Rigid diaphragm

Fig. A1 Data collection form.

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Please cite this article in press as: S.A. El-Betar, Seismic vulnerability evaluation of existing R.C. buildings, HBRC Journal (2016), http://dx.doi.org/10.1016/j.hbrcj.2016.09.002