

# Seismic Risk Assessment of Existing School Buildings in Egypt

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**Abstract**— In recent decades, Egypt has had high volume of investments a high density in the existing densely populated school buildings throughout Egypt. It should be noted that the buildings seismic design issued during the construction phase have been inadequate design. Consequently most of the school buildings are facing a seismic risk. In this Paper numerical development of fragility assessment curve for moment resisting frame reinforcement concrete of the existing school buildings in Egypt as the case study is presented herein. The Ambient Vibration Analysis (AVA) has provided a reliable means to evaluate the actual dynamic characteristics of the existing schools buildings, which can be concluded the actual numerical fragility curve of seismic risk mitigation.

The study succeeded to present reliable fragility curves to show the peak ground acceleration for 50% probability of exceeding slight, moderate, and sever damage of ground acceleration approximating from 0.15 to 0.4 g using three real scaled time history of earthquakes Al-Aqaba occurred in 1995, Northridge occurred in 1994, and El-Centro occurred in 1940, respectively , to assess the structural seismic risk performance levels of existing Egyptian schools, for different return period earthquakes, for lives saving, repair costs, and the strengthening works after and/or pre- earthquake excitation.

**Keywords**— Existing Schools, Seismic risk, Fragility curve, Egypt.

## I. INTRODUCTION

In the last decades of Twentieth Century, the damages that have occurred to public buildings due to earthquakes proved to be more serious than that one occurred to the private buildings. In Egypt, school considerable densely populated buildings constitute number of the public buildings. Life's losses of many people and damages levels of public and private buildings so that, evaluating the seismic performance of buildings and proposing some effective methods to rehabilitate them against earthquakes is an essential step toward hazard mitigation and risk assessment. The moderate earthquake that has occurred in October, 1992 near Cairo caused severe damages to hundreds of schools. Many schools have collapsed while others have suffered different degrees of damage [1,2]. Typical projects developed by the Ministry of Educational have been used

throughout all governorates until the year 1992. After 1992, typical projects by the General Authority for Educational Buildings (GAEB) have been implemented. These typical projects are similar architecturally with minor differences regarding the foundation design ranging from one site to another. This is particularly useful in regions of moderate and slightly seismicity, such as Egypt and the Middle East zone, where Egyptian General Authority of Educational Buildings (EGAEB) is currently developing retrofit programs, in addition to setting a pre-earthquake plan.

In order to evaluate the probability of structure is exposure to damages due to various ground motion excitations; the fragility curve can be a good thermometer for pre-earthquake excitation estimation, moreover the planning tools, retrofitting and strengthening of the existing buildings structures; [1]. Developing fragility curves for a specific type of building is a probabilistic method to estimate the probability that the building will exceed a specific state of damage for a definite value of the seismic intensity parameter.

The complex structures the material properties and boundary conditions are often not well known. In addition, inclusion of general damping in finite element analysis is still deemed as a main parameter that has significant effects on the actual dynamic characteristics of these existing schools that has effect on the numerical assessment of fragility curve of schools. Ambient Vibration Analysis is concerned with field testing measurements, which is used to obtain a model for the modal analysis; it can be defined as Experimental Modal Analysis (EMA), which is based on the measured vibration modes of the structure. Hence this generally results in producing a large amount of data, there is a need to compress the amount of data by developing an experimental parametric model of the studied structure that essentially contains the same information as the original vibration data. Generally, the process of establishing a model using the data is called System Identification, [2]. Dynamic system identification will be an important step to obtain the real numerical fragility curve of schools.

Framed Reinforcement Concrete (FRC) structures are commonly found in many countries. FRC represents approximately 75% of the building stock in Egypt; In the recent years, several studies in seismic risk assessment and development of fragility curves for existing RC buildings

are a matter of great concern by the researchers, [3, 4]. Fragility curves of reinforcement existing buildings can be developed empirically as well as analytically. Empirical fragility curves are usually developed based on the damage reports from past earthquakes. When actual reinforcement concrete building damage and ground motion data are not available, analytical fragility curves can be used to assess the performance of building, [5, 6].

The main objective of this study is to find analytical fragility curves for Egyptian typical reinforced concrete school to describe the probability of a structure is exposure a specific damage state due to various levels of ground excitation. This can be used for prioritizing retrofit, pre-earthquake planning, and loss estimation tools based on numerical approach taking into account, the ambient vibration measurements of study's cases reveal results describing the real dynamic behaviour of the structure, the structural parameters and the variation of the input ground motion. Prior to the newly established Egyptian loading seismic regulation code for the building structures and bridges (ECP 201(1993,2003, and 2008))[7,8], the existing schools have been designed using the seismic design coefficient method (scaled Dynamic effect factor (I) to be matching with Egyptian seismic map accelerations values).

## II. EGYPTIAN SCHOOLS BUILDINGS CONFIGURATION

In Egypt, the school buildings systems have different certain prototypes prepared by the General Authority for Educational Buildings (GAEB). Provincial directorates have are responsible for construction supervision of these schools. Although these typical projects display minor differences from one province to another, which are architecturally similar.

The (GAEB) has classified the school buildings into seven models. This classification has been done based on two main parameters. The first is numbers of classrooms (capacity of school); while the second is soil profile properties; (bearing capacity, and foundation system) that depends on site condition and soil investigation results.

The structural systems of school buildings designed by (GAEB) are as follows:

1- Reinforcement concrete skeleton system with an ordinary frame action among beam columns connections where no special steel details are available. Bearing wall system has effect partially where all block works are done before casting the horizontal structural system (slabs and beams) in a traditional construction sequence, especially in the urban areas of Egypt.

2- Schools are designed and constructed in accordance with ECP- 201 [7] for the loading and ECP-203 [8] for reinforcement concrete design to resist the vertical loads

and lateral stability of the building. Before 1992 an old school has been designed under the vertical loads only.

The structural system at all existing buildings are Moment Resistance Frame (MRF) to earthquake lateral load stability with filling block works for all perimeters and internal partitions that have significant effect on the dynamic performance of school as it shown at an experimental study conducted by Sobiah, and Ezz El-Arab 2012,[2]. Author, and Sobaih, worked to evaluate and determine the ambient vibration analysis of these types of schools, to determine the actual dynamic characteristics [1,2]; as shown in Fig.1 (a) and (b), respectively. the measurements analysis of experimental results will be used to determine the actual dynamic characteristic of this type of Egyptian existing schools taking into consideration all construction and non-structural parameters, to be verified with the 3D finite element that will be considered as an analysis to assess the seismic risk of existing schools.; as it will present in details in the following sections.

## III. NUMERICAL VERIFICATION VERSUS AMBIENT VIBRATION EXPERIMENTAL RESULTS

The dynamic characteristics of the existing schools are considered as one of the important parameters that affecting the numerical analysis, for expecting the fragility curve of these existing school buildings for two reasons; The first reason is the construction sequence in which the slabs and beams are being cast after the building block works for perimeter and internal partition with a heavy density block work, for that the actual system will not be pure Skelton system, but it will be working a partially bearing wall system in addition to the ordinary frame moment resistance. The second reason is the actual behaviour of the block works filled frame of school, which will improve the overall stiffness of school building as a bracing system.

In case of disregarding these two actual parameters, the study will be more conservative moreover, no code formula will be calculating the actual dynamic characteristics of existing school buildings. Hence, the experimental investigation work is the ideal methodology to measure and assess the dynamic characteristics of buildings [9, 10], using the ambient vibration testing techniques. For this purpose, the dynamic response of the chosen school buildings under ambient conditions have been measured using the Kinometrics Altus K2 Strong Motion Accelerograph [11] with an internal triaxial force-

Balance accelerometer in addition to other nine sensors to have a total number of 12 channels, as shown in Fig. 2.



(a): Case 1: Preparatory School with 36 classrooms, (Sehaim School).



(b): Case 2: Secondary School with 8 classrooms, (El-Gaafaria school).

Fig. 1: Photos of Study Cases, Schools

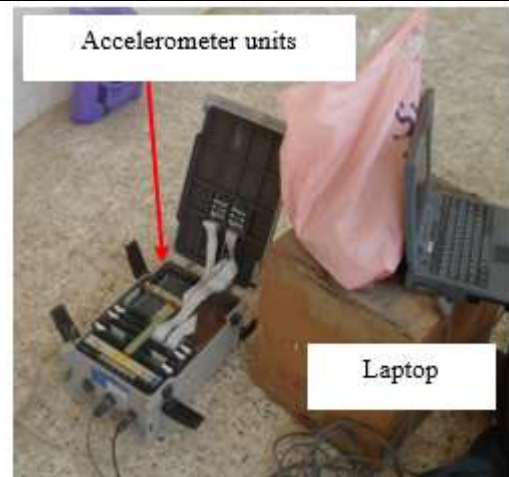


Fig. 2: The Kinemetrics Altus K2 Strong Motion Accelerograph.

These channels are used with cables with different lengths (5, 10, 15, 65, and 120 meters). With ambient vibration measurements, the time history of the forcing function cannot easily be measured. Therefore, the peak amplitude method [12] is used herein to extract the model parameters. In this method, the natural frequencies correspond to peaks of the response in the frequency domain.

Fig. 3 shows the recorded amplitudes versus the angular frequencies for the chosen school buildings, i.e., Sehaim and El-Gaafria schools, respectively (study cases of Delta School located in North of Egypt). The ambient vibrations for each school were measured for 60, 120, and 180 seconds in a trial to verify the accuracy of results. The available recording channels of the accelerograph have been used to perform the modal testing process in the two perpendicular directions, i.e., longitudinal and transversal, for each school building, to estimate the first three time period of each building.

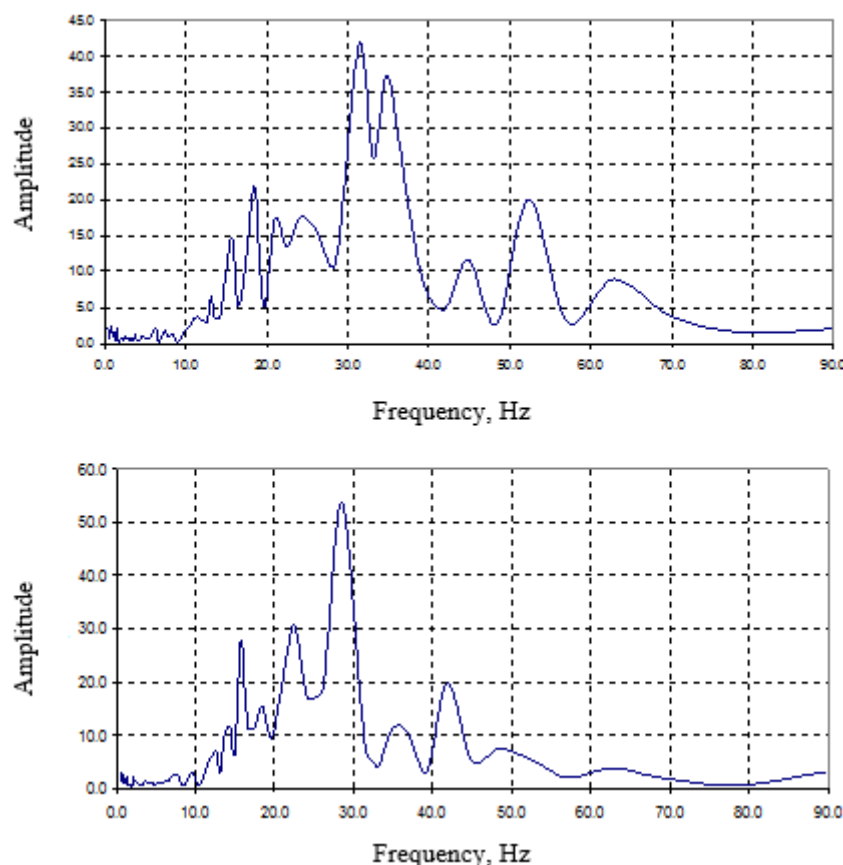


Fig. 3: The Fourier Response in Transversal and Longitudinal Directions of study cases Schools.

In Figs 4 and 5 the ambient vibration measurements results for the two schools buildings with different file durations compared to 3D Finite Element Modelling (FEM) of school taking into consideration the non-structural parameters of block work filling ordinary frame of building as it explained above; concrete strength of reinforcement concrete elements with different concrete strength  $F_{cu}$ = 20, 25, and 30 Mpa, and the density of block works that used in wall partitions. It should be noted that the first three measured natural periods agree well for different file durations. Also 3D finite element modelling will be improved and enhanced taking into consideration all other real parameters to get the most compatible dynamic characteristic to be matching with the real ambient vibration experimental results.

The paper succeeded to provide 3D simulation using advanced finite element modelling (Etab Ver.15),[13] taking into consideration all non-structural elements like block works and traditional construction procedure that have significant effect on the overall dynamic characteristics of existing school as it cleared in Figs 4 and 5. Based on that verification the seismic analysis can be done for this actual finite element, so as to start the seismic

risk effects, to estimate fragility curve of Egyptian existing schools.

#### IV. EARTHQUAKE EXCITATION TIME HISTORY

The earthquake analysis of existing schools will be done under different real time history for three different ground excitations, which are selected to match the seismicity of the school site. One of them is Al-Aqba Earthquake, which shocked Egypt in 1995. The focused point of this earthquake was Al-Aqaba Gulf east of Egypt. The other two earthquakes El-Centro, occurred in 1940, and Northridge, occurred in 1994. The time history of the earthquakes was scaled in consistence with the seismic requirements for the zone of study cases, as shown in Fig. 6. The peak ground acceleration which was used has motion ranges. This range is suitable and compatible to the micro zonation map of seismicity characteristics in Egypt zone. This scaling of earthquake ground acceleration will analyse the results in comparison with the other dynamic and equivalent static load methods in a more rational manner. The response spectrum of the above mentioned earthquakes excitations are presented at Fig. 6.



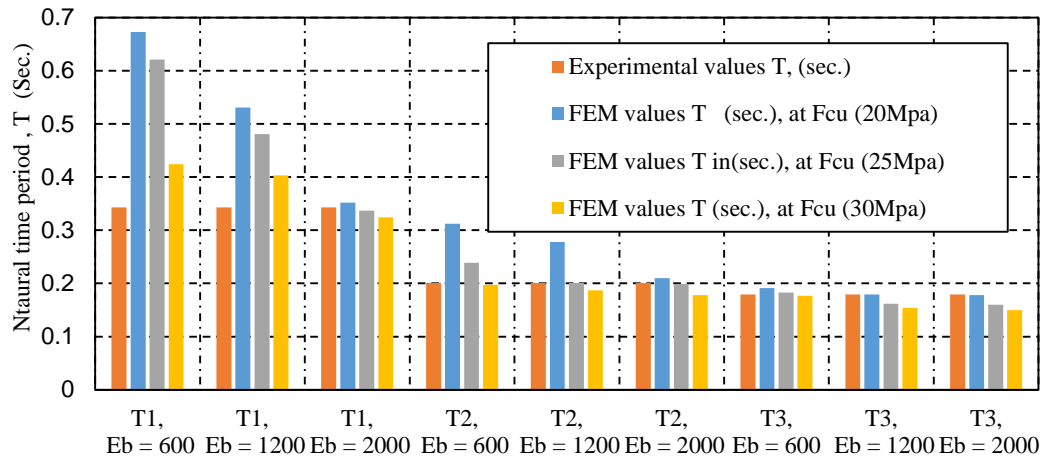


Fig.4: Seihaim School Verification of Finite Element Natural Time Period Versus The Experimental Measured Time Period, with Different Block,  $E_b = 600, 1200$ , and  $2000 \text{ Kg/M}^3$ , Respectively. ( $E_b$  young's modulus for bricks), ( $F_{cu}$  Concrete strength)

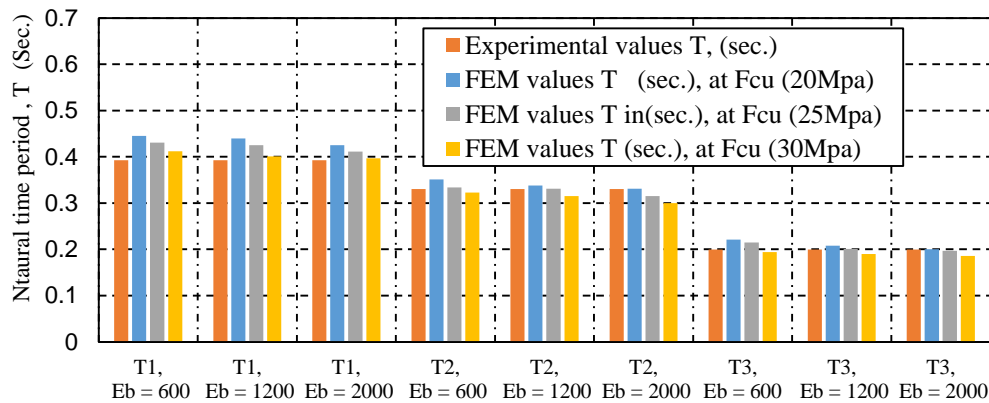


Fig.5: El-Gaafaria School Verification of Finite Element Natural Time Period Versus The Experimental Measured Time Period, with Different,  $E_b = 600, 1200$ , And  $2000 \text{ Kg/M}^3$ , Respectively. ( $E_b$  young's modulus for bricks), ( $F_{cu}$  Concrete strength).

## V. SEISMIC RISK ANALYSIS AND DAMAGE LEVEL OF EXISTING SCHOOLS

The seismic risk performance assessments methodology is briefly reported in this paper. The flowchart methodology is presented at Fig.7.

As shown at Fig.7, the first step in the methodology of seismic risk assessments of existing school buildings in Egypt was the spread and deep investigation in order to understand the peculiarity of seismic performance of the existing school structures. Egyptian existing schools were widely characterized. In this part, a procedure for performance assessment of typical Egyptian school prototypes is established. Egyptian schools are selected prototypes that are designed and constructed based on old EPC, which ignored the seismic lateral stability of the schools.

For the old existing Egyptian schools that was designed and constructed before 2008, they can be classified to two types; the first was designed only under gravity loads as an

intermediate frame system and the second type which can be considered as not fulfilling the structural design requirements where were completely ignored the lateral stability of seismic requirements for super and sub-structural elements.

In order to achieve the main target of this research, the damage levels of existing building are missing in Egyptian Codes EPC, revisions; consider as biggest challenges for any structural design, to estimate the seismic risk of the existing school buildings or any other buildings. Due to the ASCE2007 [10], EMS98 [14]. In ASEC2007 and EMS98, the Damage Level ranges (DL1) for the non-structural damage to severe damage, led to total collapse (DL5). In general, evaluation of the existing buildings the structural engineer and users accept damage level that safe the lives of users and also, give chance for economic repair and rehabilitation works. Then, at each condition of lateral deformation, it should associate a limit state reflecting a section yield level (a specific limit for the Ductility Ratio

of Columns (DRC) and/or beams (DRB)).

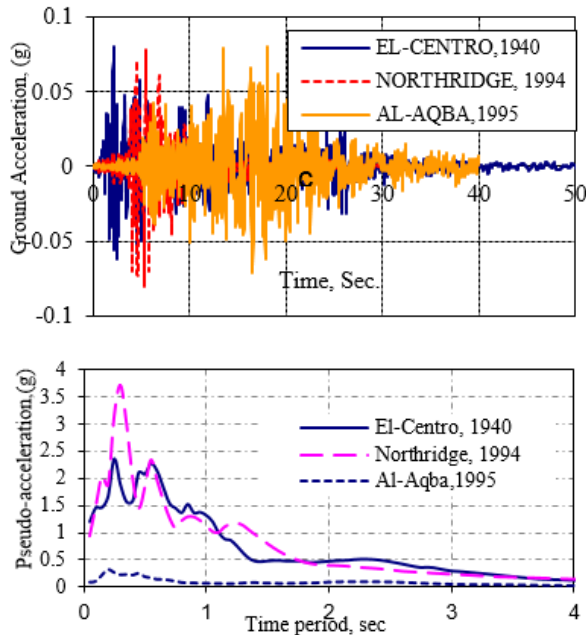


Fig. 6: Scaled Time History Ground Acceleration and Response Spectrum of Earthquakes, Respectively.

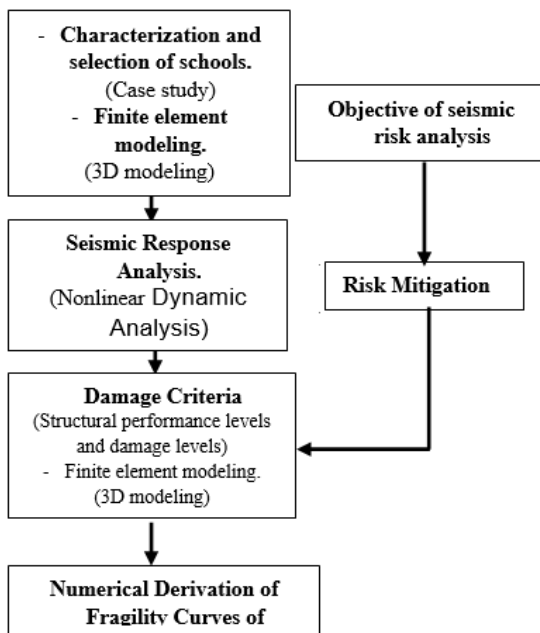


Fig.7: Methodology of Seismic Risk Analysis of Existing Buildings.

Table 1 presents the four damage levels descriptions[10,14], all existing school buildings systems are MRF treated in Egypt, which makes it necessary to build a specific damage levels based on inter storey drift relationship. Relative drift will be determined based on the Ductility Ratio of beams and columns being gotten from the finite element modelling, taking into consideration the fill frame action and actual dynamics characteristics that were measured experimentally at the field.

Egyptian Delta's schools included at the study cases were analysed in respected three different earthquake ground motions; the first is the earthquake that occurred in Egypt 1995 (Al-Aqaba) and the other two earthquakes that occurred in other parts of the world were scaled the same peak ground acceleration to be adapted with the same one occurred in Egypt as it presented in Fig 6 for the scaled time history and response spectrum, respectively.

Table.1: Damage Criteria to Define Structural Performance (Beam and Columns Considered As Primary Components for Damage Level), [10, 14].

Damage Level	Description	Performance	Ductility Ratio (D.R)
D.L. (4)	Heavy (collapse and near collapse)	For columns and beams considered as primary components the deflection exceed 75% of the ultimate value and at most one structural elements exceed the ultimate value.	$1.00 > DRC_{max}$ $\chi > 0.75$ $1.00 > DRB_{max}$ $\chi > 0.75$
D.L. (3)	Significant/Medium Structural	For columns and beams considered as primary components the deflection not exceed 75% of the ultimate value	$DRC_{max}$ (0.25- 0.75) $DRB_{max}$ (0.25- 0.75)
D.L. (2)	Moderate/ Low structural	For columns and beams considered as primary components the deflection not exceed 25% of the ultimate value.	$DRC_{max}$ $< 0.25$ $DRB_{max}$ $< 0.25$
D.L. (1)	Weak/ No structural Damage	For columns and beams, the deformation not exceeds elastic limit. Only inter-story drift-sensitive non-structural components are considered.	

## VI. SEISMIC RISK AND ANALYTICAL FRAGILITY CURVE OF EGYPTIAN SCHOOLS

There are different methods that can be used for evaluating the seismic risk and estimating the fragility curve of the existing buildings. It can be divided into two main groups by [6, 9] : (1) Obtaining a damage index level by means of

inspection; Estimation of vulnerability based on expert's judgment in case of lack of information about buildings; (2) Evaluation of the damage index level through structural analysis which can be measured analytically based on the ductility ratio of beam and columns in the skeleton building structures. This method that will be presented in the paper, to evaluate the seismic risk and estimate the fragility curve of existing schools in Egypt.

Finite element Models are based on structural analysis provide a greater quantity of results, but reliability depends on their capacity to represent real seismic behavior. Which is based on expert's judgment requires a large number of professionals with in-depth knowledge of the problem having a proven experience, while statistical evaluations which are based on a real damage data can only be applied in zones of moderate or high seismicity where the sufficient data are available.

Therefore, fragility curves have been developed analytically from nonlinear dynamic analyses of typical school prototypes in Egypt. Since damage states are mostly related to structural capacity (C) and the ground motion intensity parameter is related to structural demand (D), the Damage Level (DL) gives the probability that the seismic demand may exceed the structural capacity through determining the ductility ratio of beams and columns.

Under various levels of ground motion excitations selected to be matching with micro-zonation of the ground motion in Egypt; in Fig. 8 the maximum ductility ration of beams, and columns in each floor level of school buildings are presented under different earthquake ground acceleration motions. Fig. 8 a,b,and c show the beam and column ductility ratios under Al-Aqaba,1995, Northridge,1994, and El-Centro,19940, respectively.

As shown in Fig 6 the ground motion acceleration was scaled for two local earthquakes Northridge and El-Centro to be matching and complying with the Egyptian peak Ground Acceleration (PGA) which was presented in Fig.6 for the response spectrum curves for three earthquakes in longitudinal and transversal directions, respectively.

The ductility ratio of columns are higher than the beams by 70% to 80% under all different earthquakes ground acceleration motions, the frame action of the block walls filling among the columns is one of the important parameters that works to improve the overall performance of the super structure of school buildings, where it works as a bracing action at the lower floor levels where the value of base shear and lateral momenta are bigger than the high floor level, The ductility percentage of columns is decreased on top floor levels reaching between 20% to 7% respectively in the third and fourth floor levels, respectively as shown in Fig. 8. The fragility of a structure (or component) is determined with respect to "capacity". Capacity is defined as the limit the seismic load before

failure occurs. Therefore, if Peak Ground Acceleration (PGA) has been chosen to characterize seismic ground motion level, then capacity is also expressed in terms of PGA. In what follows, and in order to simplify the notations, we will consider that PGA as being chosen to characterize the seismic ground motion. The capacity of the structure, is generally supposed to be log-normally distributed [Sobaih et al.2012], [15].

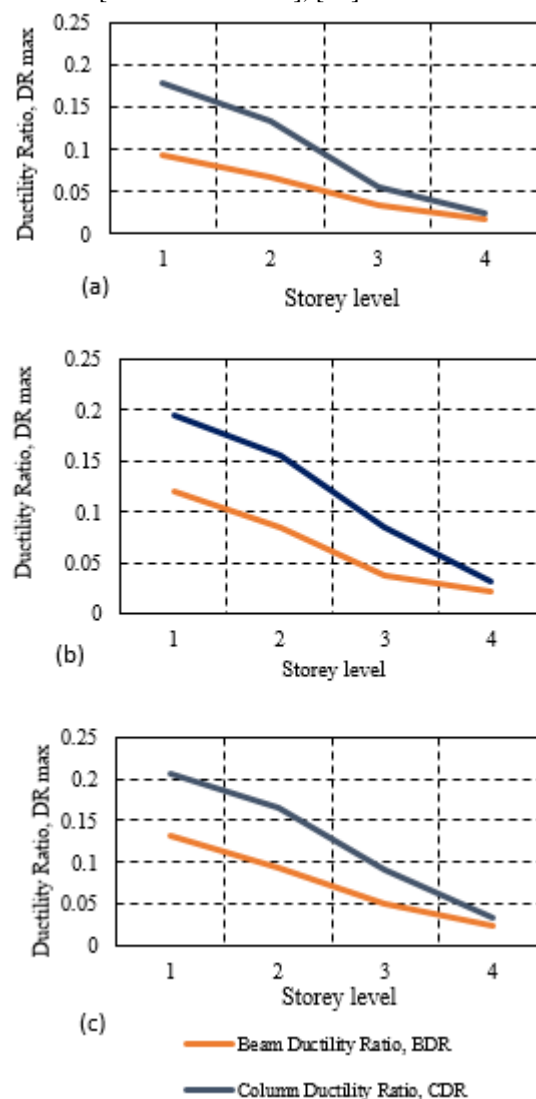


Fig. 8: Maximum Ductility Ratio (DR), of Beam and Column in each Storey levels for Different earthquake ground excitations, (a) Al-Aqaba, 1995, (b) Northridge, 1994, and (c) El-Centro, 1940, respectively.

Beams and columns ductility ratios are the key elements of a seismic probabilistic risk assessment of seismic hazard analysis, seismic fragility evaluation for each component and super structure. These maximum ductility ratios of beams and columns elements allow for the proper risk quantification of the installation, that is the evaluation of failure probability due to all possible earthquake events, which is defined based on the relevant damage level definition that is defined previously in detail at Table 1.

The Seismic Probabilistic Risk Assessment (SPRA) analysis of Egyptian schools (case studies) have been carried out for different PGA value starting from 0.15 up to 0.4g, to be matching with the expected earthquake ground motion accelerations as per EPC-301; in order to assess the seismic safety of existing school buildings or new schools in futures; as shown at Fig.9.

Fig.9 presents the probabilistic seismic hazard analysis that leads to an estimate of the probability of occurrence of different levels of earthquake ground motions at the studied sites. This means that the entire range of possible earthquakes, is considered as potential initiating event and not only design earthquake. A seismic hazard analysis results in the establishment of hazard curves  $H(a)$  giving the probability of annual excess of ground motion level  $a$ . In general, the output of hazard analysis is a family of curves, each is corresponding to a confidence level and thus accounting for uncertainty in the estimation of seismic hazard. The failure probability is due to the fact that a seismic event is obtained by "convolution" of seismic hazard curve with fragility curve, which is by calculating the total probability by integrating is:

$$P_f = \int_0^{+\infty} P_f(a) \frac{d}{da} (1 - H(a)) = - \int_0^{+\infty} P_{f/a}(x) \frac{dH(a)}{da} da \quad (1)$$

The paper succeeded to present fragility curves associated with peak ground acceleration of 0.15g and 0.2g as being slightly damaged that means the schools RC super structures elements section has a linear behavior for these ground acceleration scales; which can be considered the safety of school structure composed of superstructure. For the peak ground acceleration value being greater than 0.25g to 0.3g, the schools behavior can be considered as moderate damage and the super structures RC elements section will be needing an enhancement procedure, especially for the moderate seismicity zone area in Egypt like North Coast of Egypt, Eastern of Suze Gulf, and Al-Aqba Gulf. For other peak ground acceleration value being greater than 0.35g, the pier will be suffering a severe damage due to such an earthquake excitation and schools super structures RC section will not be safe which is potentially to be subject to a sudden shear failure.

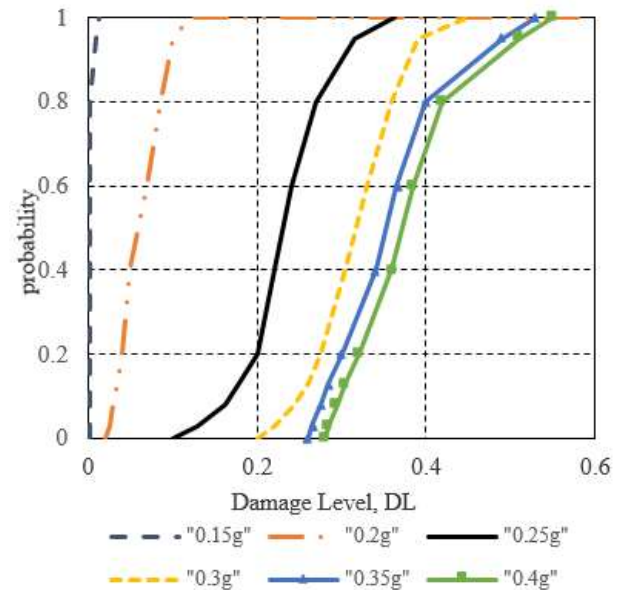


Fig.9: Analytical fragility curve of Egyptian school with different peak ground acceleration.

## VII. CONCLUSION

In Egypt, neither schools buildings damages nor their performance have been officially reported after earthquakes which occurred in earlier times. Consequently, this paper proposes a seismic risk and assessment evaluation method based on a structural nonlinear analysis for RC skeleton system of the schools, super structures taking into consideration the real dynamic characteristics that are measured experimentally from field to get into consideration the effect of filling block works that has bracing action on the lateral stability of the buildings. The proposed model is based on the characterization of the maximum ductility ratios of the beams and columns in super structural of school buildings, the damaged level being defined based on the ductility ratios of beams and columns which are under different PGA values.

The paper succeeded to present an easy, accurate, and new analytical propose method to get on the fragility curve of Egyptian schools that are of the most identical statues. The presented fragility curves describe the probability of structure being damaged beyond a specific damage for various levels of ground excitations PGA from 0.15g up to 0.4g. This method will be used for prioritizing the retrofit, pre-earthquake planning, and loss estimation tools. This is particularly useful in certain regions of a moderate seismicity, like Egypt.

The presented reliable fragility curve of the existing schools in Egypt will allow a simple and optimized rules for practical planning, to support the decision makers in Egypt (Egyptian General Authority of Educational Buildings (EGAEB)), as well as consultants simple, applicable, and economic retrofitting strategies can be



defined and integrated in the event of a seismic risk and its mitigation prior to ground motion excitations.

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