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COMPARATIVE STUDY ON CODE-BASED LINEAR EVALUATION OF AN EXISTING R.C. SCHOOL BUILDING BEFORE AND AFTER 1992 EGYPT EARTHQUAKE

Ahmed Abdelrahem Farghaly

Civil and Architectural Building, Faculty of Industrial Education,
Sohag University, Egypt

Ali Mohamed Abdallah

Civil Engineering Department, Faculty of Engineering,
Kafrelsheikh University. Kafrelsheikh , Egypt

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ABSTRACT

Building codes did not include requirements for special seismic detailing of reinforced concrete structures until the 1970's when several earthquakes demonstrated the need for more ductile design. These buildings are vulnerable to numerous failure modes including: failure of column lap splices; strong beam/weak column failures; captive column failure; punching shear failures in flat plate slabs; and shear and axial load failure of columns with wide transverse reinforcement spacing. A discontinuity in stiffness and strength at the bottom story, due to a soft story, often results in a concentration of earthquake damage at the building base. Several examples of past earthquake behavior are given in this report as well as discussion of various retrofit options.

Gravity load designed old school buildings had been heavily damaged by the October, 1992, Egypt earthquake in the regions near the epicenter. 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 cause the accumulation of students over the stair, which led to the death of some students. Samples of old school buildings in Egypt were selected for evaluation to determine the deficient aspects of these buildings. Finally, the research sheds the light on the best public behaviour against earthquakes.

The aim of this study is to investigate the code-based procedure of seismic performance assessments of existing buildings and to determine the seismic performance levels of a case study reinforced concrete building, which represents typical existing building stock in Egypt, as well as comparing the consequences of linear static analysis procedures.

Keywords: ECOL2008 ; Egyptian Code ; Seismic Assessment; Linear Static Analysis ; School building.

1. INTRODUCTION

Determination of seismic performance of existing buildings has become one of the key concepts of structural analysis topics after recent earthquakes. Considering the need for precise assessment tools to determine the seismic performance level, most of earthquake hazardous countries try to include performance based assessment in their codes. Recently, Egyptian Code 2008 (ECOL2008) also introduced linear assessment procedures to be applied prior to building retrofitting. In this paper, a comparative study is performed on the code-based seismic assessment of RC school buildings with linear static methods of analysis, selecting an existing RC school building. The basic principles dealing the procedure of seismic performance evaluations for existing RC school buildings according to ECOL200 before and after 1992 Egyptian Earthquake will be outlined and compared. Then, the procedure applied to a real case study building is selected which is exposed to 1992 Earthquake in Egypt, the seismic action of Ms =7. 3 with a maximum ground acceleration of 0.5g It is a five- storey RC school building with a total of 17.5 m height, composed of orthogonal frames, symmetrical in y direction and it does not have any significant structural irregularities. It was reported that the building had been not damaged during the 1992 earthquake. The computations show that the performing methods of analysis with linear approaches using (ECOL2008) independently produce similar performance levels of collapse for the critical storey of the structure. The computed base shear value according to (ECOL2008) is much higher than the requirements of the Egyptian Code, while the selected ground conditions represent the same characteristics. The main reason is that the ordinate of the horizontal elastic response spectrum for (ECOL2008) is increased by the soil factor. The demand curvatures from linear methods of analysis of (ECOL2008) before and after 1992 Egyptian Earthquake together are almost similar.

Performance based design and assessment in structural engineering is becoming more important in the past several years. The decision of the analytical method for performance-based assessment is being a new topic and the λlinear elastic methods of analysis have been used for a long time.

Structural assessment and design concept with the principle of performance criteria based on the displacement and strain are especially put forward and developed for the realistic safety and rehabilitation of structures in the United States' earthquake regions.

The damage caused by the 1989 Loma Prieta and 1994 Northridge, in California – USA, made it possible to reconsider not only the current performance criteria regarding the strength of materials but also add more realistic criteria based on displacement and strain. With this concept, Guidelines and Commentary for Seismic Rehabilitation of Buildings – the ATC 40 [1] Project by the Applied Technology Council (ATC), and NEHRP Guidelines for the Seismic Rehabilitation of Buildings – FEMA 273 [2] and FEMA 356 [3] by the Federal Emergency Management Agency (FEMA) have been developed. Later on, in order to examine the results further on, the ATC 55 and FEMA 440 [4] have been developed. Besides these organizations, different projects like Building Seismic Safety Council (BSSC), American Society of Civil Engineers (ASCE) and Earthquake Engineering Research Center of University of California at Berkeley (EERC-UCB) contributed them. With the aid of these projects and papers, the assessment of the performance the existing structures in the quake zones and the redesigning of buildings according to their earthquake performances could be possible.

On the other hand, there exist also some researches regarding the performances of structures according to ECOL2008 [11].

Recent earthquakes, which occurred in Egypt made it compulsory to assess the safety of structures. Thus, in addition to the Egyptian Code of 2008, the new version of Egyptian Code (ECOL2008) was issued in September 2008 [11] in which the assessment and rehabilitation of structures have been added. The researchers state that linear analysis method under the scope of ECOL2008 result not with same performance levels of non linear method. However, it is noted that linear analysis method is relatively more conservative on the basis of component performance damage level [7, 8, and 9].

2. CODE-BASED PERFORMANCE ASSESSMENT PROCEDURES PERFORMANCE REQUIREMENTS

Building performance levels or limit states are chosen discrete levels of building damage under earthquake excitation.

ECOL2008 chapter eight defines three limit states, related to structural damage:

No Collapse Requirements (NC): The structure is not damaged all or some of it. Repair of structural components is not required, because their resistance capacity and stiffness are not compromised after earthquake by 10% of design possibility (Return period 475 years ago).

Damage Limitation Requirements (LD): the design requirements are to resist the earthquake loads without crakes after earthquake by 10% possibility of design (Return period 95 years ago).

Increase of Earthquake safety (IS): the structures specify by its importance, each structure has an importance factor this factor depends on the return period of the earthquake ((Return period 475 years ago for traditional building).

Egyptian Code 2008 defines the seismic performance as the expected structural damage under considered seismic actions. Seismic performance of a building is determined by obtaining storey-based structural member damage ratios under a linear or nonlinear analysis. Member damage levels are classified as shown in Figure 1. The building performances are as in the following:

Ultimate limits states (UL): For each main direction that seismic loads affect, for each collapse shape that caused dangerous to life.

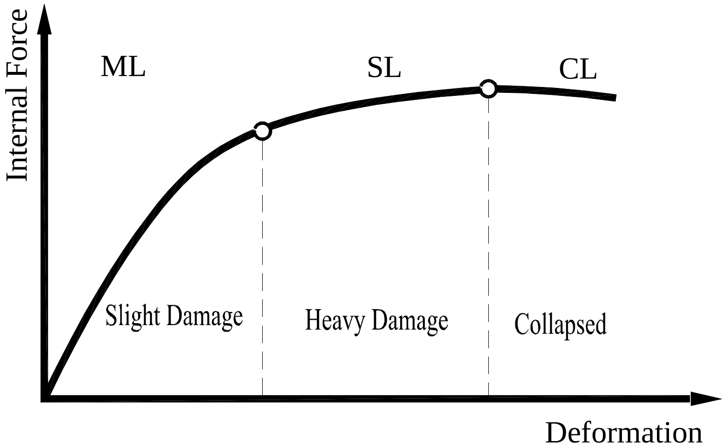


Figure 1: Cross-sectional Member Damage Limits (ECOL2008)

Serviceability limit state (SL): For each main direction that seismic loads affect, these limits affect the safety using of the structures.

A target performance assessment objective for a given building consists of one or more performance level for given earthquake hazard level. Recommended return periods to corresponding limit states are given in Table 1.

Table 1). ECOL2008 Recommended Return Periods

Limit States	**Return Period**	**Probability of Exceedance**
No Collapse Requirements (NC)	475 years	10% / 50 years
Damage Limitation Requirements (LD)	*90 years*	*10% / 50 years*
Increase of Earthquake safety (IS)	*475 years*	*10% / 50 years*

3. LINEAR STATIC ANALYSIS PROCEDURES

Depending on the structural characteristics of the building, *Lateral Force Method of Analysis or Modal Response Spectrum Analysis* may be used as linear-elastic methods. Static procedure may be used whenever the participation of higher modes is negligible.

V = Z.I.K.C.S.W ………..…(1); for old code design;

Z earthquake factor zone

I important factor

K structural system factor of building

C structure factor (C = 1/15√ T > 0.12), T fundamental natural period of building (T =0.1N or T = 0.09 H /√B; N number of storeys, H height of building and B width of building perpendicular to earthquake direction in meter).

S soil factor

W equivalent dead load plus half live load

$$F_j = \frac{W_j.H_j(V - F_T)}{\sum\limits_{i=1,N}(W_i.H_i)}; F_T = 0.07T.V \ ; \ \ldots\ldots\ldots(2)$$

F_T excessive horizontal force in the plan of roof
W_j load of floor, H_j height of floor from foundation level.

$$F_b = \frac{S_d(T_1)\lambda W}{g} \quad \text{……….. (3); for new code design,}$$

F_b total horizontal base shear force
S_d (T_1) elastic response spectrum
T_1 basic period of the structure
λ Correction factor (1~0.85)
W total weight of the structure

$$F_i = \left[\frac{u_i W_i}{\sum_{j=1,n} u_j W_j}\right]. F_b \text{ ……… (4) Or } F_i = \left[\frac{Z_i W_i}{\sum_{j=1,n} Z_j W_j}\right].F_b \text{ …………(5);}$$

F_i horizontal force affecting the floor
F_b total horizontal shear force from earthquake
u_i, u_j displacement of masses m_i, m_j
W_i, W_j weight of masses m_i, m_j
n number of storeys over the foundation level
Z_i and Z_j heights of masses m_i, and m_j

Design schools before the 1992 earthquake on gravity loads only without taking in consideration the effect of earthquakes but after the 1992 earthquake the details of construction building resist earthquake take into consideration in design and construction.

The load patterns, used for static analyses, are not able to represent the deformed shape of the structure when higher modes are put into effect. The participation of higher modes depends generally on the regularity of mass and stiffness and on the distribution of natural frequencies of the building with respect to seismic fundamental frequencies. Linear procedures (lateral force method of analysis and modal response spectrum) are applicable when the structure remains almost elastic or when expected plastic deformations are uniformly distributed all over the structure. The *Equivalent Seismic Load Method* is suggested in ECOL2008. The main objective of these methods is to compare demands by using unreduced elastic response spectrum with the existing capacity of elements, then to evaluate damage levels on the basis of elements with obtained demand-capacity ratios, and to determine the seismic performance level of the overall building. The conditions of using the equivalent seismic load method according to ECOL2008 are summarized in Table 2. In the determination of base shear force, unreduced (elastic) response spectrum is utilized.

The distribution of the horizontal seismic forces according to ECOL2008 *Lateral Force Method* depends on modal shape of the structure at the fundamental period. On the other hand, in *Equivalent Seismic Load Method* lateral force distribution is related to storey masses and their elevation.

Time history analysis is a more realistic method to represent the true effect of earthquakes on the building so, for the comparison states for 1992 Egyptian earthquake using the method of ECOL2008 and time history analysis method to stand up with which an existing structures will resist these kind of earthquake.

Figure 2 shows the typical structural plan of old version school building designed before 1992 Egyptian earthquake. The system as shown consists of one stares and one R.C. frame in one direction as shown also the cross section of beam is satisfied the gravity loads but columns (small cross sections as shown in Table 4) is not and will be collapse under vertical loads of gravity and earthquake loads.(f_{cu}=18 Mpa and f_y= 240 Mpa)

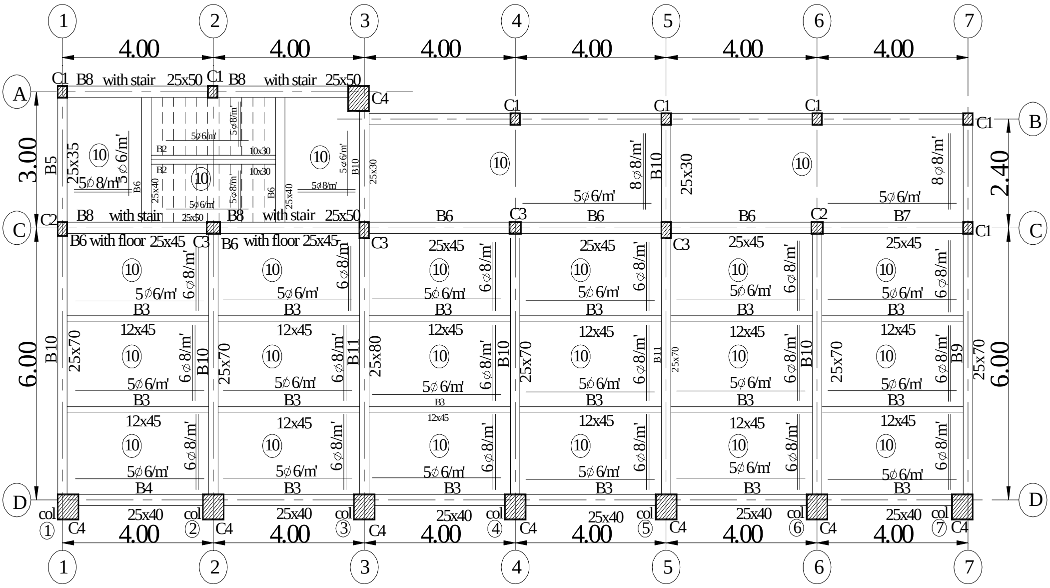


Figure 2 Typical Storey Plan (designed before 1992 Earthquake)

Figure 3 shows the typical structural plan of new version school building, which designed after the 1992 Egyptian earthquake, which the construction details and design take into consideration. As shown, the frame system constructed in two orthogonal directions and the sections of beams satisfied the gravity and earthquake loads. The column cross sections carry gravity and earthquake vertical loads safely as cross section illustrated in Table 5.

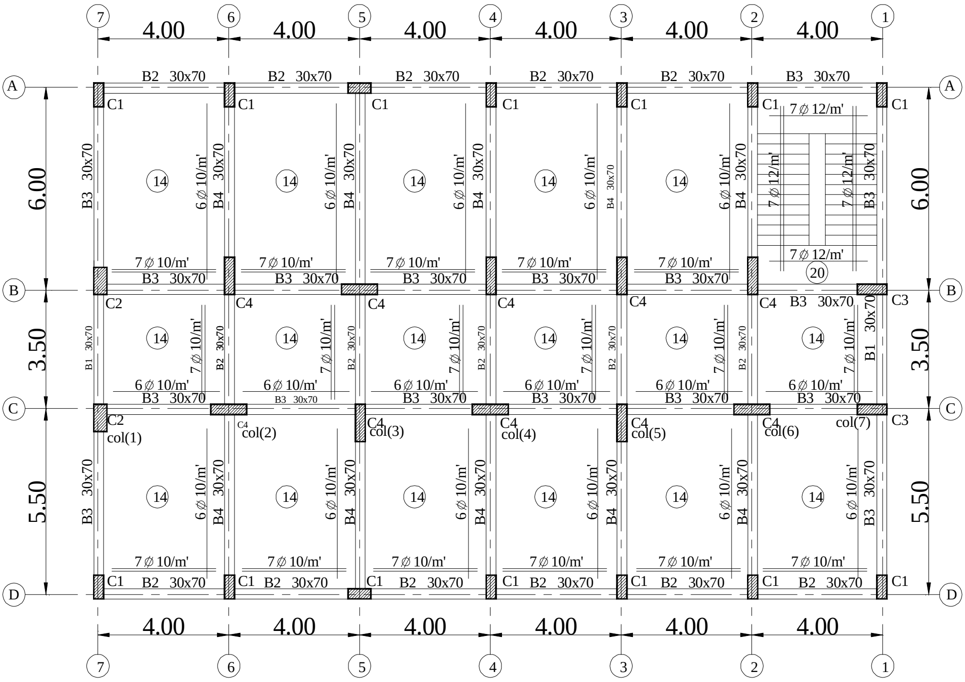


Figure 3 Typical Storey Plan (designed after 1992 Earthquake)

4. CASE STUDY ON AN EXISTING RC BUILDING (DESIGNED BEFORE AND AFTER 1992 EGYPTIAN EARTHQUAKE)

On 12 October 1992, an earthquake, magnitude mb= 5.9 and Ms = 5.2, hit the City of Cairo, Egypt. It was this century's largest earthquake in northern Egypt with related destruction in the City of Cairo, the Nile Valley and the Nile Delta areas. The case study building has five storeys with a total of 14.65 m height and it is composed of orthogonal frames, symmetrical in y direction and does not have any structural irregularities. The planar dimensions are 24 x 15 m = 360 m^2 with six spans in x and three spans in y directions, (Figure 2). It was initially designed and constructed according to the 2008 Egyptian Code.

Storey heights are 3.50m. Slabs are having a thickness of 14 cm and they are modelled as a rigid diaphragm at each storey level. The column dimensions are as shown in Table 4. The in-situ tests for material properties reports that the characteristic compression capacity of the concrete is 25 MPa and the characteristic yielding capacity of the reinforcement is 360 MPa, which are lower values than the ones given in the original project.

The computed base shear value according to ECOL2008 is much higher than the actual earthquake effect, while the selected ground conditions represent the same characteristics (Figure 3). The main reason is that the ordinate of the horizontal elastic response spectrum for ECOL2008 is increased by the soil factor as shown in Figure 3, where, S_e (T) elastic horizontal response spectrum, T time period, a_g ground acceleration (actual a_g = 0.5g calculated a_g = 0.25g), T_B, T_C values of constant response spectrum, $\square_1$ important factor (=1.2), T_D constant value of spectrum, □ damping ratio (=1), and S soil factor.

Table 2: values of T_B, T_C, T_D, and S.

Subsoil class	S	T_B	T_C	T_D
C	1.5	0.1	0.25	1.2

Table 3: Dimensions and reinforcements of columns in each storey for an old design model before 1992 Earthquake (M.S.)

Sym.	**Sections**	**Reinforcement**
C1	25×25 cm	4φ13mm
C2	25×30 cm	6φ13mm
C3	25×35 cm	6φ13mm
C4	25×55 cm	8φ13mm

Table 4 : Dimension and reinforcement of columns in each storey for a new design model after 1992 Earthquake (M.S.)

Sym.	**Ground floor**		**1st, 2nd floor**		**3rd,4th floor**	
	Sections	**Reinforcement**	**Sections**	**Reinforcement**	**Sections**	**Reinforcement**
C1	30×70 cm	16φ18mm	30×70 cm	16φ16mm	30×70 cm	16φ12mm
C2	40×80 cm	16φ18mm	40×80 cm	16φ16mm	40×80 cm	16φ12mm
C3	30×90 cm	20φ18mm	30×90 cm	20φ16mm	30×90 cm	20φ12mm
C4	30×110 cm	20φ18mm	30×110 cm	20φ16mm	30×110 cm	20φ12mm

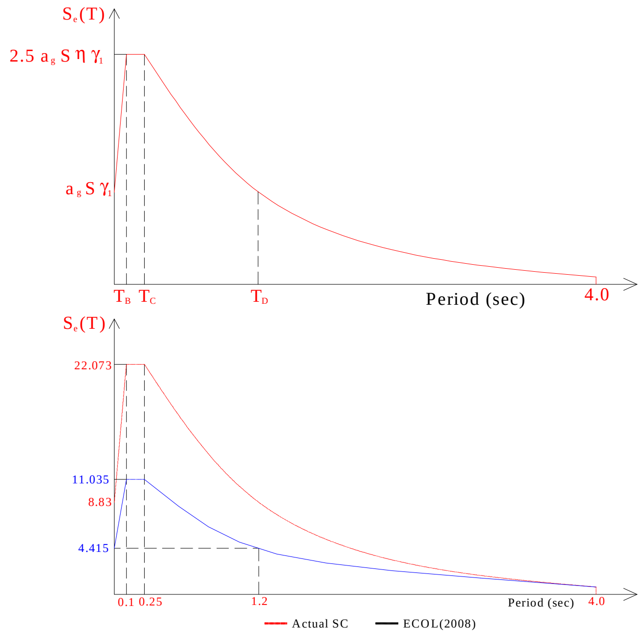
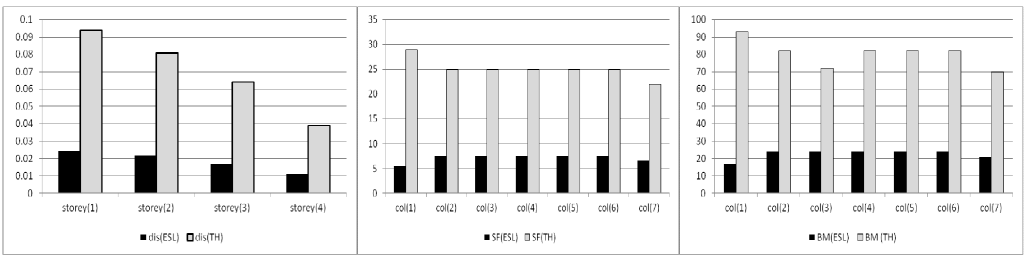


Figure 3: Horizontal elastic response spectrum curve

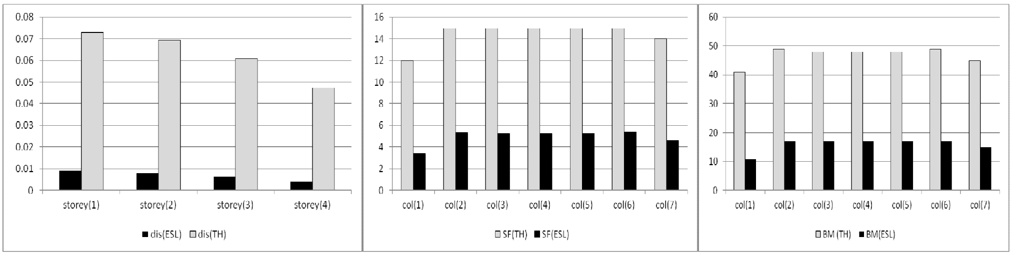
Figure 4 shows a comparison between the code method and the real earthquake effect on displacement of each floor, base shear force and base bending moment of the outer column row of the school building. Columns shear force in the code case analysis equals nearly 2.5 times the shear force in real (time history analysis) case.



i) Storey displacement (m) ii) Base shear of the outside columns (ton)
iii) Base bending moment (m.t)

Figure 4: Old School Design Straining Action, i) Storey Displacement, ii) Base Shear of Outside Columns and iii) Base Bending Moment

Figure 5 shows a comparison between the code method and the real earthquake effect on displacement of each floor, base shear force and base bending moment of the outer column row of the school building**.**



i) Storey displacement (m) ii) Base shear of the outside columns (ton)
iii) Base bending moment (m.t)

Figure 5: New School Design Straining Action, i) Storey Displacement, ii) Base Shear of Outside Columns and iii) Base Bending Moment

5. CONCLUSIONS

In this study, performance based assessment methods and basic principles given in ECOL2008 and real time history analysis (TM) are investigated. After the linear elastic and non-linear approach are outlined as given in two cases of analysis, the procedures of seismic performance evaluations for existing RC school buildings according to ECOL2008 and TM are applying for a real three dimensional case study building and the results are compared.

The computations show that the performing methods of analysis with approaches using either ECOL2008 or TM independently produce a difference performance level for the critical storey of the two structures. The cases study buildings are found to be as in safety performance level for new version school building designed after the 1992 Egyptian earthquake but not for the one who designed before the earthquake. The computed base shear value according to TM is higher than the ECOL2008 Code, while the selected ground conditions represent the same characteristics. The main reason is that the ordinate of the horizontal elastic response spectrum for ECOL2008 is increased by the soil factor. It is also observed that the demand storey drafts obtained from the two methods of analysis are difference in values. The ECOL2008 code for design such kinds of building satisfy conditions for earthquake loads. For the safety conditions, the old version of the school building, which affected by the 1992 Egyptian earthquake of not it must be strengthened as the technical procedure to resist any future Earthquakes, which the study showed the probably collapse if they expose to anther earthquake.

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دراسة مقارنة لتقيم أداء مباني المدارس الخرسانيه المقامة قبل

وبعد زلزال مصر 1992م على اساس خطية الكود

قبل زلزال 1992 بمصر لم تكن تأثير أحمال الزلازل تؤخذ في الاعتبار عند التصميم الانشائى للمنشآت الخرسانية وكان من ضمن المباني التي تم تنفيذها في هذه الفترة مدارس التربية والتعليم وفي عام 1988 م تم إنشاء الهيئة العامة للأبنية التعليمية لتقوم بتصميم وتنفيذ المدارس وفي عام 1990م صدر الكود المصري لتصميم وتنفيذ المنشآت الخرسانية رقم 203 وفي عام 1992م حدث زلزال مصر الشهير والذي كان له اثر كبير في انهيار العديد من المدارس وعلية كانت تصميمات المدارس المقاومة للزلزال طبقا لكود الخرسانة رقم 203 وكود الأحمال رقم 201 لسنة 1993م وعلية تم تصنيف المدارس طبقا لمقاومة الزلازل إلي نموذجين الأول النموذج القديم وهي مدارس ما قبل زلزال 1992م والنموذج الثاني الحديث وهي المدارس التي نفذتها هيئة الأبنية التعليمية بعد عام 1992م ثم جاء بعد ذلك كود الأحمال الجديد في عام 2008م .

وعلية كانت هذه الدراسة للوقوف علي مدي قدرة مدارس التربية والتعليم بمصر علي مقاومة الزلازل طبقا للكود المصري للأحمال رقم 201 لسنة 2008م سواء كانت المدارس تم تنفيذها قبل أو بعد زلزال 1992م . وقد أثبتت الدراسة أن مدارس النموذج الأول القديم غير مقاومة للزلازل وتحتاج لتدعيم حتى تكون آمنة أما مدارس النموذج الثاني الحديث المنفذة بعد عام 1992م فهي آمنة ومقاومة للزلزال طبقا لكود الأحمال رقم 201 لسنة2008م .