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Seismic Analysis of Existing School Buildings Using Different Egyptian Seismic Provisions

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Abstract

This paper presents a comparative study for seismic analysis of a certain class of existing school buildings which are considered as one of the important and wide spread buildings in Egypt. The study focuses on a comparison between all versions of the Egyptian Code of Practice for loading (ECP-201), versions published in 1993, 2003, and the draft of final version October, 2008], and the Regulations of the Egyptian Society of Earthquake Engineering (ESEE, 1988). Base shear and base moment values are calculated using all of the above mentioned seismic provisions. The controller straining actions of these provisions are then compared with those obtained using response spectrum and time history analyses using real ground excitation of pervious earthquakes (Al-Aqba, 1995, Northridge, 1994, and El-Centro, 1940). All these earthquakes are scaled to be matched with the maximum ground acceleration for the study zone. It has been found that high variation between the base shear and base moment obtained using the ECP versions specified different analysis methods and in comparison with the ESEE and Earthquake analysis. This high variation make the new ECP-201 (October, 2008) will be need to recontemplate.

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1. Introduction

It is well known that there are three methods for structural earthquake analysis. These methods are the Equivalent Static Load method (ESL), the Response Spectrum Method (RSM), and the Time History Analysis (THA). The (ESL), and the (RSM) methods are generally used for linear analysis of the dynamic response of structures. In various forms, (THA) method has been widely used in the earthquake-resistant design of special structures such as very tall buildings, offshore drilling platforms, dams, and nuclear power
plants. For a number of years; however, its use is also becoming more common for ordinary structures as well.

The (ESL), and (RSM) analysis procedures were simplified from the general case by restricting consideration to lateral motion in a single plane. Only one degree of freedom was required per floor for this type of analysis. In recent years, with the advent of high-speed, desktop computers, and the proliferation of relatively inexpensive, user-friendly structural analysis software capable of performing three-dimensional modal analyses, such simplifications have become unnecessary. Consequently, the new Provisions adopted the more general approach describing a three-dimensional modal analysis of the structure. When modal analysis is specified by the Provisions, a three-dimensional analysis is generally required except in the case of highly regular structures or structures with flexible diaphragms.

2. Major changes of seismic provisions

The research will present the significant difference points that have been applied to the seismic provisions in different ECP editions released from 1993 to 2008, and the ESEE. Table 1 illustrates the base shear formulas with the related parameters to present the major changes.

| Parameter | ESEE, 1988 | Egyptian Code Practice |
|-----------|------------|------------------------|
| Equivalent Static Load (ESL) | $V = C_s W_t$ | $V = Z I S M R Q$ |
| | $C_s = Z I S M R Q$ | $F_b = S_d (T_1) \lambda W / g$ |
| | $S_d (T)$ is the design response spectrum which is related to $(a_g, S, R, T, K, I)$ | $\gamma'_I = 0.8, 1.1, 2, 1.4$ (increase of earthquake safety) |
| Seismic hazard parameter | $Z = (0.0, 0.02, 0.04, 0.08)g$ | $Z = (0.1, 0.2, 0.3)g$ |
| Importance categories and importance factor | $I = 1, 1.3, 1.5$ | $I = 1$ or $1.25$ |
| Period effect | $T = 0.09 H / \sqrt{d}$ | $C = 1/15 \sqrt{T}$ |
| Correction factor | N.A. | $\lambda = 0.85$ or 1.0 |
| Damping correction | N.A. | $0.95 \leq \eta \leq 1.2$ |

The major difference between the ECP-1993 and the ECP-2003 was remarked by the new adoption of the response spectrum method that presented the pseudo acceleration anchored to Peak Ground Acceleration (PGA). Also, the soil parameter has a big effect on the response spectrum curve. On the other side, the two newest provisions ECP-2003 and ECP-2008 have a similar base shear formulation except the existence of the importance factor $\gamma'_I$, either in response spectrum or in the base shear equation which yields final identical base shear. It is clear from the initial comparison how the base shear value obtained from ECP-2003 and 2008, is greater than the value obtained of ECP-1993. The value of base shear that was
obtained from the ECP-2008 and 2003 when used in the elastic theory it must be reduced by a factor of the 1.4 or 1.28 for ECP-2008 and ECP-2003, respectively.

The ESEE presented the response spectrum method in additional to equivalent static load with many factors not taken into consideration in the ECP-2003 and 2008 like material, risk, and construction quality factors. All of these factors are still neglected in all ECP editions till 2008.

3. Case Study of School Buildings in Egypt

The Egyptian General Authority for Educational Buildings has divided the school buildings to seven models according to two main items. The first is the capacity of class rooms, while the secondly is soil classification that depends on the school location. In the present paper, the middle of Delta region has been chosen for the studied cases. First school is the preparatory school in a small village called Seheim that contains 36 class rooms; divided on a ground floor plus four typical floors. The ground floor is used for general services. Second type of school is the secondary school in a small village called El-Gaafria that contains 8 class rooms. The school includes a ground floor used as a services area and four typical floors containing the class rooms. Both cases have the same soil characteristic that prevails in the middle of the Delta region. Besides, the selected schools have complete data obtained from the Egyptian General Authority for Educational Buildings.

Comparison of code fundamental natural period with experimental values using the ampient vibration tests on the studied cases has been presented in (Sobaih and Ezz El-Arab, 2010), where the natural time period of each case study was calculated using different Egyptian codes and compared with USA code (IBC 2006). Also the error percentage of the natural time period compared to the experimental time period was presented. The big error percentage is one of the major reasons that reflected in the results especially in ESL where the equivalent static force mainly depended on the calculated natural dynamic characteristics for the structure.

4. Ground Earthquake Excitations

Three different ground excitations are selected to match the seismicity of the school site. One of them is Al-Aqba earthquake, 1995 which shock Egypt in 1995, and the other two earthquakes are El-Centro, 1940, and Northridge, 1994. Figure 1a shows the acceleration time history of the three earthquakes ground excitation Al-Aqba, 1995, El-Centro, 1940, and Northridge, 1994, respectively. Both the El-Centro, 1940 and Northridge, 1994 earthquakes are scaled to match the seismic requirements for the zone of cases study as it is clear in Figure 1b. This scaling of earthquake ground acceleration will make the results comparison with other dynamic and equivalent static load methods are more rational. The response spectrum of the above mentioned earthquakes excitations are presented in Figure 2 in the longitudinal and transversal directions, respectively.

5. Numerical Results

The results of RSM and THA, using the indicated three ground excitations, are compared with those obtained from the equivalent static loads using all the Egyptian codes editions and the ESEE regulations for considered school buildings. This comparison is illustrated in Figures 3, 4, and 5. The results of the equivalent static method for ESEE, ECP-1993, ECP-2003, and ECP-2008 are presented in Figure 3 for the school building case-1. The analysis results are presented in both longitudinal and transversal directions of the school building. To get a clear vision of the response of each technique analysis as compared to the most
accurate analysis of the time history analysis for the Egyptian earthquake excitation Al-Aqba, 1995, an error factor $E$ was calculated as following:

$$E = \left[ \frac{A_{\text{analysis technique}} - A_{\text{analysis of THA (Al-Aqba, 1995)}}}{A_{\text{analysis of THA (Al-Aqba, 1995)}}} \right] \times 100$$

Where: $A$ is the absolute peak response of school building by different earthquake analysis techniques, i.e., ESL, RSM, or THA. The values of $[E]$ the error percentage are listed in Table 2.

The maximum base shear force value from the ESEE has good agreement with those from the T.H.A. due to Al-Aqba, 1995 earthquake excitation. Where as the base shear value due to ECP-1993 is very small with unexpected values having an error percentage of -88%. The ECP-2003 and 2008 have results more logical compared to the old version of ECP where the error percentage dose not exceed 28%. It is worthy to note the insignificant difference between the results of base shear and moments in both direction of school building when it is compared to the other analysis methods R.S.M. and T.H.A.; this can be explained the weakness of this approximate method that is not effected by the change of building stiffness in both directions like the others methods. ECP-2008 has underestimated base shear and moment especially the values that is presented in Figures 3, 4, and 5 should be divided by 1.4, 1.28 for ECP-2003 and ECP-2008, respectively to has the working values that will be compared to others codes where other codes results are in working state.

Table 2: The error percentage ($E$) due to different analysis techniques compared to T.H.A. Technique using Al-Aqba earthquake.

| Analysis method | Code provision | E% (Error percentage) |
|-----------------|----------------|-----------------------|
| **Longitudinal Direction** | **Transversal Direction** | **Base Shear, Q** | **Base Moment, M** | **Base Shear, Q** | **Base Moment, M** |
| ESL.           | ESEE           | 1.5                   | 2.1               | 3.1               | 5.8               |
|                | ECP-1993       | -88.0                 | -83.3             | -86.0             | -60.0             |
|                | ECP-2003       | -23.0                 | -16.7             | 17.0              | 50.0              |
|                | ECP-2008       | -27.1                 | -20.8             | 12.0              | 35.0              |
| R.S.M.         | ESEE           | 4.2                   | 32.6              | 22.0              | 112.5             |
|                | ECP-2003       | -16.5                 | 4.2               | 2.1               | 15.0              |
|                | ECP-2008       | 1.0                   | 25                | 2.0               | 40.0              |
| T.H.A.         | El-Centro, 1940| -41.0                 | -32.3             | 3.4               | 70.0              |
|                | Northridge, 1994| -3.4                 | -29.2             | 1.5               | 10.0              |

The maximum base shear and moment due to response spectrum analysis techniques are presented in Figure 4 in the longitudinal and transversal directions, respectively. The results due to ECP-2003 by (RSM) are more closed to base shear with the earthquake analysis due to AlAqba, 1995 compared to (ESL) by the same code ECP-2003.

Figure 5 presents the earthquake analysis results of the three different ground excitation earthquakes, Al-Aqba, 1995, El-Centro, 1940, and Northridge, 1994, respectively. Despite of the unified value of the three peak ground excitation to match the seismcity zone, there is a big change between the bases shear and moment. The reason for may be attributed to different frequency contents of three different earthquakes. This is clear from the response spectrum curves as shown in Figure 2.

Frequency content strongly affects the response characteristics of the structure. In structure, the ground motion is amplified the most when the frequency content of the motion and natural frequencies of the structure are close to each other. Also, the difference between the duration of strong motion has an effect on
the results. Duration of strong motion has a pronounced effect on the severity of shacking, as it is clear in Al-Aqba, 1995 compared to El-Centro, 1940. A ground motion with moderate peak acceleration and long duration may cause more damage than a ground motion with large accelerations and shorter duration.

The straining actions that are generated from the Northridge earthquake compared well with Al-Aqba, 1995 earthquake contrary to El-Centro, 1940. This can be explained by the large difference in the response spectrum curve behavior of El-Centro earthquake compared to the other earthquakes, as shown in Figure 2.

6. Conclusions

A comparative numerical analysis based on all available earthquake resistance techniques that used in the Egyptian code provisions started from (201-1993, 2003) and ended by (201-2008), and ESEE-1988 regulations. Earthquake analyses with different ground excitations also are presented using the (T.H.A) method. The results of this numerical investigation are compared with regard to the base shear and moment calculated using the Equivalent Static Load (ESL) and the simplified Response Spectra Method (RSM) to assess and verify the impact of utilizing any of these methods on the response of school buildings in Delta of Egypt. A practical emphasis is aid to discuss the influence of response modification factor introduced in ECP-2008. Relying on the investigations and discussions presented in this study, the following conclusions can be drawn out.

- Egypt still suffers from the lack of available data of time history records for earthquake events registered in Egyptian land.
- The basis for the ESL procedure and its limitations were discussed above. It is adequate for most regular structures; however, the designer may wish to employ a more rigorous procedure for those regular structures where the ESL procedure may be inadequate.
- Extreme variation in the base shear and moment obtained from ECP-1993 compared to others ECP-2003, 2008, and ESEE-1988 with error percentage exceeding 90%.
- The simplified ESL and RSM analysis carried out on the middle of Delta-Egypt, in peak ground acceleration and soil conditions, revealed that the normalized base shear and base moment obtained using the ECP editions were less matched with real earthquake time history analysis results with error percentage reaching to 90%.
- The study provides the importance to avoid any ignoring the seismic design on the structures with height limitations, and the seismic zone in which the structure exists.
- Earthquake resistance of school buildings in Egypt need to be reevaluated considering the significant results that presented in the study, and adopt retrofitting for those schools with insufficient resistance.

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Figure 1a: Ground acceleration of earthquakes in longitudinal and transversal direction, respectively

Figure 1b: Factored Ground acceleration of earthquakes in longitudinal and transversal direction, respectively

Figure 2: The response spectrum curves for three different earthquakes in longitudinal and transversal direction, respectively.
Figure 3: The bases shear (ton) and moment (ton.m) values due to Equivalent static load method (ESL) by different codes, in longitudinal and transversal direction, respectively.

Figure 4: The bases shear (ton) and moment (ton.m) values due to Response spectrum method (RSM) by different codes, in longitudinal and transversal direction, respectively.

Figure 5: The bases shear (ton) and moment (ton.m) values due to Time history analysis under factored earthquake ground excitation, in longitudinal and transversal direction, respectively.