



Seismic Design of Steel Structures with Special Flexural Frame Based on Performance by Durability Method

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Abstract

Equivalent static, response spectrum and time history analysis are the well-known analysis methods that traditionally proposed. These methods are highly accurate but requires a great deal of time to match accelerations and the number of analyses, in the other words these methods are time consuming methods. Hence recently the structures are investigated using the durability time method, which plays an essential role in reducing the number of analyses that needs to be created; In fact, the durability time method is a new method of seismic analysis that is presented with a minimum number of time histories analysis. In this method the structure is placed under the influence of an increasing dynamic stimulation, structural response has been investigated over time and evaluated according to the corresponding response to different levels of stimulation intensity, strengths and weaknesses, and structural performance. In this study, steel folding frameworks with 5, 10 and 15 floors were investigated under two analytical methods (Time durability and Time histories methods). At first, the frameworks will be exposed under history of Imperial Governor, Kobe and Lumaprita earthquakes and analysis by finite element software ABAQUS. Then, based on the three analytical functions, the durability is investigated and the results are compared with each other. Finally, the behavior of the structures discussion and conclusion. The results show that the durability analysis method for earthquakes with higher intensity and time is more efficient, and for the Time-less earthquakes by time history method parametrically have a parametrical difference of 5%.

Keywords: Time Durability Method; Time Histories Analysis; Special Steel Folding Frame; Structural Performance.

1. Introduction

Over the several past years demands for more accurate, improved and low computational cost methods for seismic assessment of structures increased. To solve this matter, some new methods were developed which estimate structural behavior realistically due to not only taking dynamic characteristics of structure into account but also considering earthquake excitation as it takes place [1]. Considering that the earthquake movement has three components, the seismic analysis of special and sensitive structures need consideration of the effects of these components [2].

Since the method of time durability is a new method, more extensive research is needed to identify the well-known advantages or the limitations and defects of this method so that in the future this method can be found in the regulations that more fully used the threshold when the structure exceeds the arbitrary limit states (for example, permissible gravity) [3]. Development of these new methods and criteria should be mainly contributed to the amazing improvements in computational tools that have made possible the solution of sophisticated nonlinear models [4]. The Endurance Time (ET) method is a time-history based analysis and design procedure that recently has been introduced. In 2010

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Valamanesh and Estekanchi [1] are proposed a procedure for three-directional seismic analysis of buildings and investigated application of this method to several steel moment frames. Several Steel Moment Frames were designed according to INBC Code. These Frames were analyzed under ET acceleration functions in horizontal and vertical directions simultaneously and results were compared to Response History Analysis. They observed that ET method can predict the results from multi-component analysis, including vertical excitation, with reasonable accuracy. Scattering and accuracy of the results are also investigated. In 2011 Riahi et al. [5] investigated about application of the ET method in nonlinear seismic analysis of structures. in their study at first numerical procedures and optimization techniques of acceleration functions described then various steel moment frames have been exposed to a set of three acceleration functions and the results of these analysis are compared whit the results of IDA analyses. Their study show that Endurance Time is a powerful tool in nonlinear analysis of structures but for practical applications before this method can be recommended more research is required. In 2012, Amouzegar et al. [6] with IDA and ET analysis evaluated steel frames strengthened by using dampers. They observed that structural responses resulted from Endurance Time (ET) and Incremental Dynamic Analysis (IDA) and in most cases Optimization results of dampers characteristics and their positions in the structures by two methods were very close to each other .

Basim et al. [7] in 2015 investigated the application of the Endurance Time (ET) method in performance-based design of structures with and without consideration of uncertainties and a practical optimum design procedure is proposed. The ET method is used as an analytical assessment tool because of its capabilities in response estimation with an affordable computational demand. In the first step of the proposed method, ET analysis was implemented in a multi-objective optimum design procedure in order to achieve a set of Pareto optimal designs. Optimization was conducted with respect to initial cost and expected life cycle cost using a deterministic approach. For each design alternative the median damages due to probable earthquakes in its life time was estimated by the ET method, and the expected cost of earthquake consequences was calculated using Life Cycle Cost Analysis (LCCA). In the next step, a comprehensive performance assessment was carried out on a candidate optimal design considering inherent uncertainties in a framework. It is also proposed to use the ET method as the response assessment tool in this framework. Expected damage costs, fatalities and probability of collapse were estimated using a Monte Carlo approach to account for uncertainties. The advantages and shortcomings of the method are investigated by comparing the results from the ET method and recommended procedure using a suite of ground motions. The results provide a pathway towards practical use of the ET analysis method in state of the art performance-based design and probabilistic estimation of losses.

Rahimi and Estekanchi [8] in 2015 evaluating and explain collapse potential of buildings by Endurance Time method then obtained results were compared with incremental dynamic analysis (IDA) results. Their study show that computational effort using the Endurance Time method was much less than the incremental dynamic analysis. In 2016 Chiniforush et al. [9] evaluated seismic behavior of “Imam Reza Shrine” (Mashhad, Iran) which is located in a high seismic area in Iran. A comprehensive review by they show the efficiency and applicability of ET Analysis for masonry monuments and suggest modifications and interpretations to improve compatibility of the results with Time History Analysis.

According to as mentioned above results of Endurance Time (ET) method is very similar to results of incremental dynamic analysis (IDA) Even response probabilistic distributions that were predicted using the ET method match those obtained by incremental dynamic analysis [10]. Also Energy Dissipating Restraint (EDR) performance of the structures with Endurance Time (ET) method show that ET method in Seismic Control of Steel Structures can effectively reduce the computational cost [11]. In the structure that is expected to experience significant plastic deformations for the intensity levels corresponding to large return periods applying the nonlinear rigid-perfectly plastic spectra as the intensity measure is more appropriate [12].

As well as Endurance Time (ET) method can be used to quantitative measure of seismic resilience [13]. This method is reliable in capturing seismic response of off shore pile supported systems with an acceptable accuracy [14]. The ET analysis efficiently yields the structural responses for a continuous range of intensities through a single response-history analysis [15]. About endurance time excitations researcher studies show that endurance time method can successfully predict seismic demands of structures using the new generated excitations in comparison with existing ones [16].

2. Time Durability Method

The durability method is a new method of seismic analysis, in which the structure is placed under the influence of an increasing dynamic stimulation, the intensity of which gradually increases over time. Structural response has been investigated over time and evaluated according to the corresponding response to different levels of stimulation intensity, strengths and weaknesses, and structural performance.

The concept of the durability method can be explained well by using a hypotheticalal experiment. We assume that three different structures with unspecified characteristics are placed on a shaky table. Now assume that the shaking table is placed under random vibration, which gradually increases its intensity (Figure 1). At the start of the test, until the vibration range is low, all three structures will be stable. Now assume that over time and increasing the stimulation

intensity first, the structure number one, then the structure number 3 and eventually the structure number 2 will be failed. By performing this simple test, it can be concluded that structure 1, which applied to the dynamic stimulation, had the least durability and weakest performance and structure 2, which lasted longer, has the best performance. If the dynamic stimulation applied is in good agreement with the dynamic stimulation caused by the earthquake, it can be expected that the structure 2 has the ability to withstand more severe earthquakes than structure 1. In other words, by performing such an experiment, an estimate of seismic performance can be obtained from different options. In the method of durability, the above concepts are used to develop an applied analytical tool.

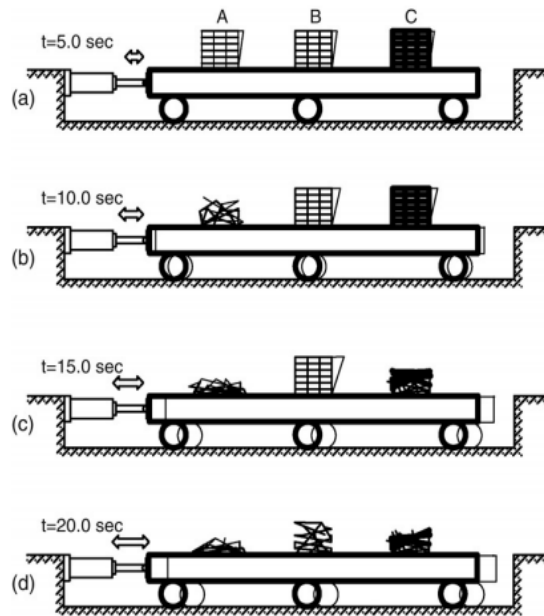


Figure 1. Hypothetical shaking table test [3]

In this method, the durability of the structure is subjected to an increasing dynamic stimulation and the maximum value of the response parameters versus time (the maximum absolute value of the response from the start to the desired time) is determined. These response parameters, depending on need, may include one or a combination of performance criteria that are used in evaluation and design. Simple parameters such as simple displacements, forces, tensions, or nonlinear responses such as plastic age or more complex failure indicators can be used with respect to the problem. Given the application of various response parameters in interpreting the results, the title of the failure index is generally used to refer to them. In this case, the failure index is, in many cases, allowed for simple parameters such as the ratio of stress or available displacement ratio.

In Figure 2, the concept of the results of the analysis of the durability time is shown schematically. For example, if the final limit of the normalized failure index is considered as a unit, it can be seen that the frame number 3 has not reached its final limit, or, in other words, lasted longer than that, so that it tolerated the intensity of stimulation the frame number 1 gets worse at a lower intensity.

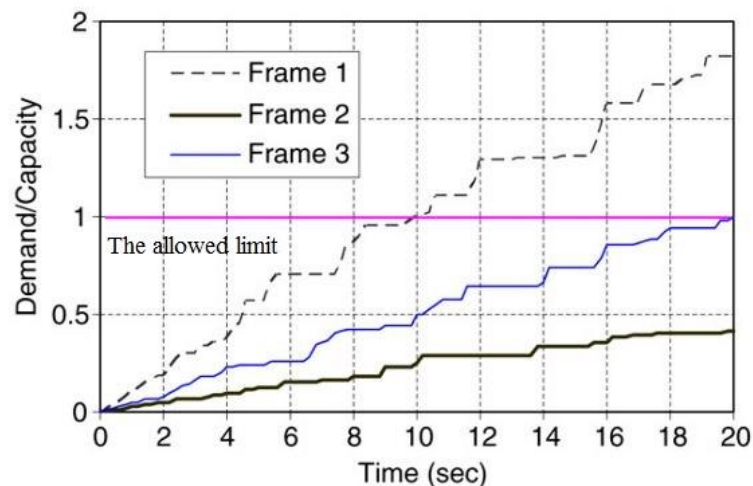


Figure 2. Structural response diagram under incremental acceleration [3]

According to Figure 2, the durability time of structure 1 is 10 seconds, the structure 3 is about 20 seconds, and the structure 2 is obtained over 20 seconds. Now, assuming that the acceleration is calibrated and the intensity of its stimulation at a given time, for example, the tenths of the time, corresponds to the intensity of the earthquake. In this example, the structure 1 reaches the limit before the required time (tenths). As a result, this construct does not meet the design criterion and is weak. But structure 2 after the base time reaches the permissible limit, and so the minimum required stamina is standard. On the other hand, structure number 2, which reaches much more than the minimum required at a time, is stronger than standard.

2.1. Duration Stimulation Functions

The practical application of the durability method depends on the generation of increasing stimulation functions that the results of the analysis by using them lead to an acceptable estimation of the effects of the earthquake in the structure. For this purpose, the concept of the response spectrum can be effectively used in the stimulus functions of durability. These functions are designed using numerical optimization methods so that the acceleration response spectrum obtained by them at any given time according to the following equation is proportional to the acceleration spectrum of the plan:

$$S_{aT}(T, t) = \frac{t}{t_{\text{Target}}} S_{ac}(T) \quad (1)$$

$$S_{uT}(T, t) = \frac{t}{t_{\text{Target}}} S_{ac}(T) \times \frac{T^2}{4\pi^2} \quad (2)$$

Where:

t: time, T: period, $S_{ac}(T)$: the template spectrum, $S_{uT}(T, t)$: the target shift, $S_{aT}(T, t)$: objective response acceleration and t_{Target} : the target time and here is the time when the scale factor is equal to unit (1.0) relative to the basic range.

2.2. Methodology Application of Durability Time Method

The first step is to provide the appropriate dynamic model of the structure or system. Simple, complex, single, double, and triple models are available depending on the case. For the initial design of the model, conventional methods (such as the static method of regulation or any other appropriate method) can be used. The model should fit with the objectives and degree of design accuracy. The next step is to select the ET Excitation Functions (ETEFs) according to the desired spectrum of the design. Time histories analysis is performed using the stimulation time functions of durability. In plotting the response time diagram, the desired response values are plotted in terms of the maximum absolute magnitude of the response to the desired time. In accordance with the method and regulation used, the response values are compared at the time or target times corresponding to the intentions of the target with the permitted values. If the answer is not appropriate, the modified plan and re-analysis will be done. If the plan is acceptable, the plan's optimality will be considered in the next step. If there is a possibility to optimize the design, the design is re-modified and the analysis is repeated.

An interesting point in the proposed methodology is the durability of its integrity, which is matched to application in the design of various structures and systems that are sensitive to earthquakes, whether to design new structures or to evaluate and improve existing buildings using models Simple linear or with a variety of geometric behavioral modalities and materials that can be used.

2.3. Specification of Existing Duration Exit Functions

The major difference is the durable record in the range of their target pattern. Another difference is the range of period covered in their production, which is important in nonlinear applications. Other differences during the record are the time step, the initial scale, which is specified in the record file. The production of the functions of the durability has progressed gradually and is divided into generations in terms of developmental stages. In the first generation, records of time-lapse compatibility with the spectrum disappeared when increasing. These records were only used in the early papers that explained the concept of the method of durability.

In the second generation of records, an increase in spectrum proportional to the spectrum of the model was performed using numerical optimization in the linear spectral range, which was also used for long-term spectral analysis for nonlinear analysis. Third generation records of time durations in the nonlinear range have also been optimized. In the fourth generation, compatibility has been recorded for the duration of the motion and the cycle of motion in the record production process. Figure 3 shows the general schematic of using the method of durability to better understand the researchers.

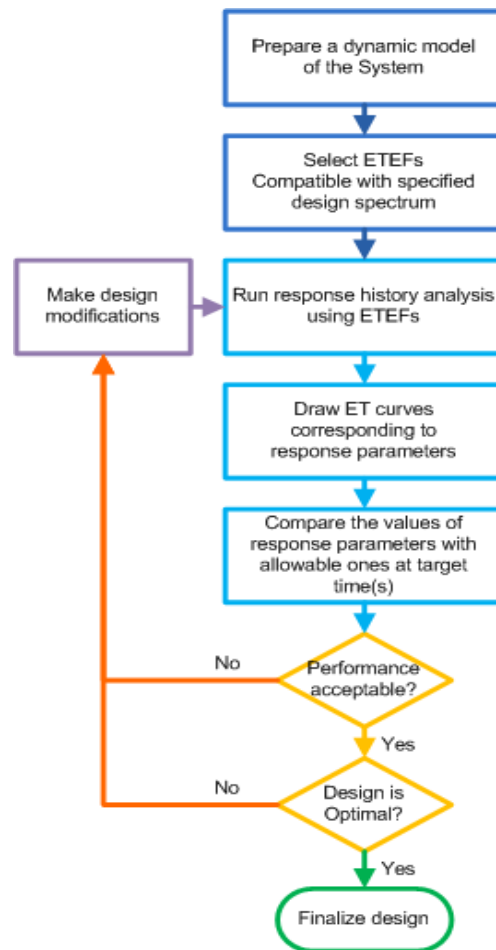


Figure 3. General methodology for using the durability method [3]

3. Examples

In this research, a structure of 5, 10 and 15 floors with three spans in both of x and y direction and 3 meters in length and height by finite element software ABAQUS is investigated. The pins of the columns and the connection of the beam to the pillars are tight. In this section, at first, the structure will be exposed under history of Imperial Governor, Kobe and Lumaprita earthquakes. Then, based on the three analytical functions, the durability is investigated and the results are compared with each other. Figure 4 shows the modeling of structures in ABAQUS. Also shown in Figure 5 are the records used. In Figure 6, the analysis functions used are displayed.

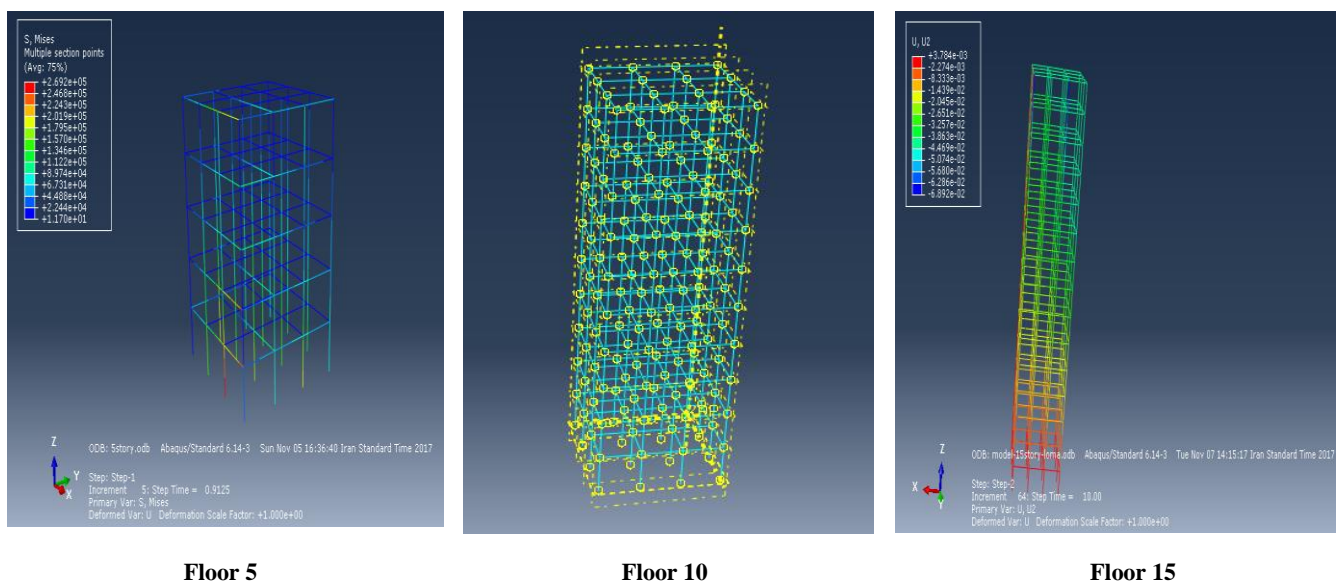
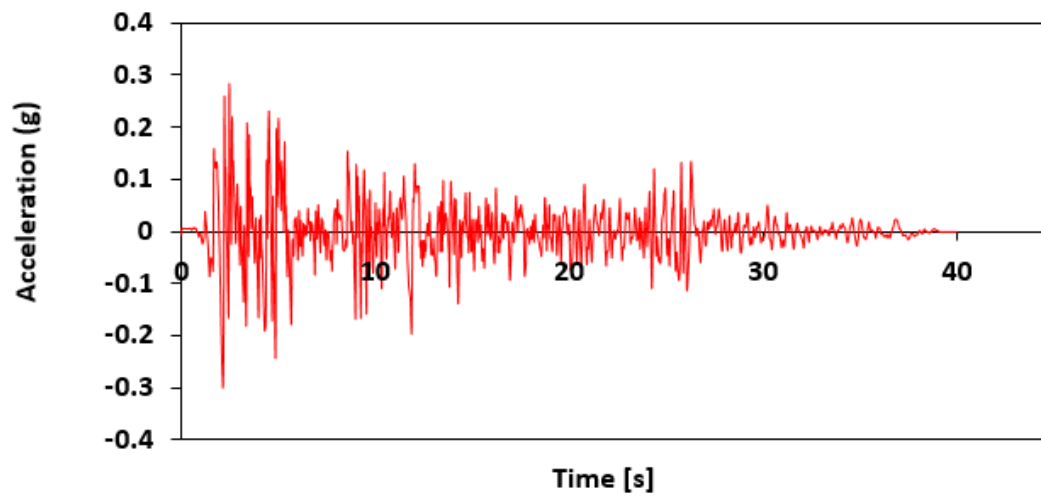
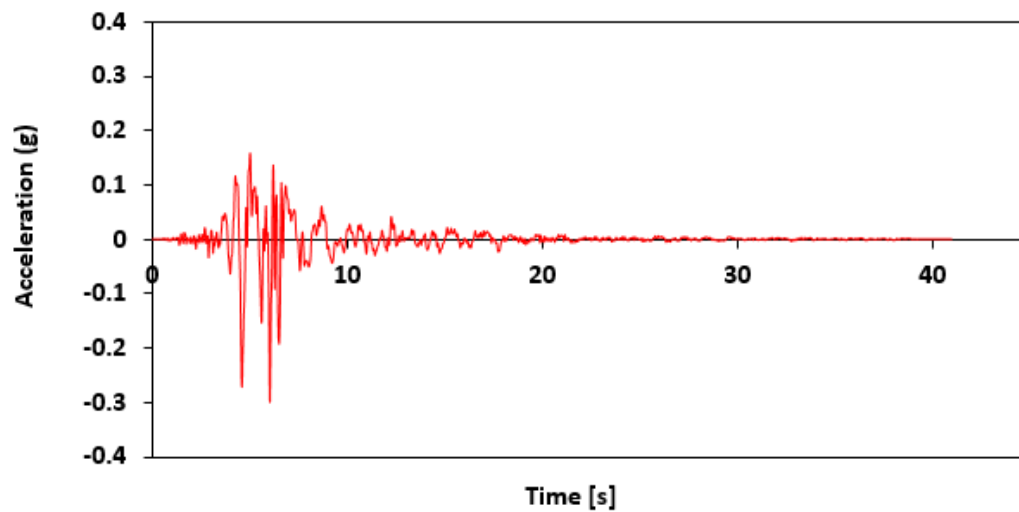


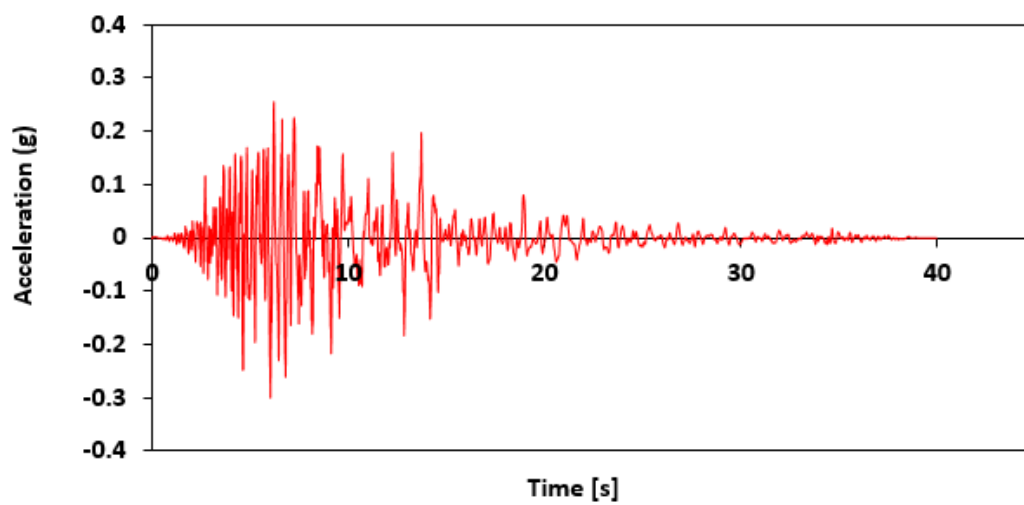
Figure 4. Modeling of structures in ABAQUS



A: Imperial Earthquake record



B: Kobe Earthquake Record



C: LumaPrieta Earthquake Record

Figure 5. Earthquake records used in this study

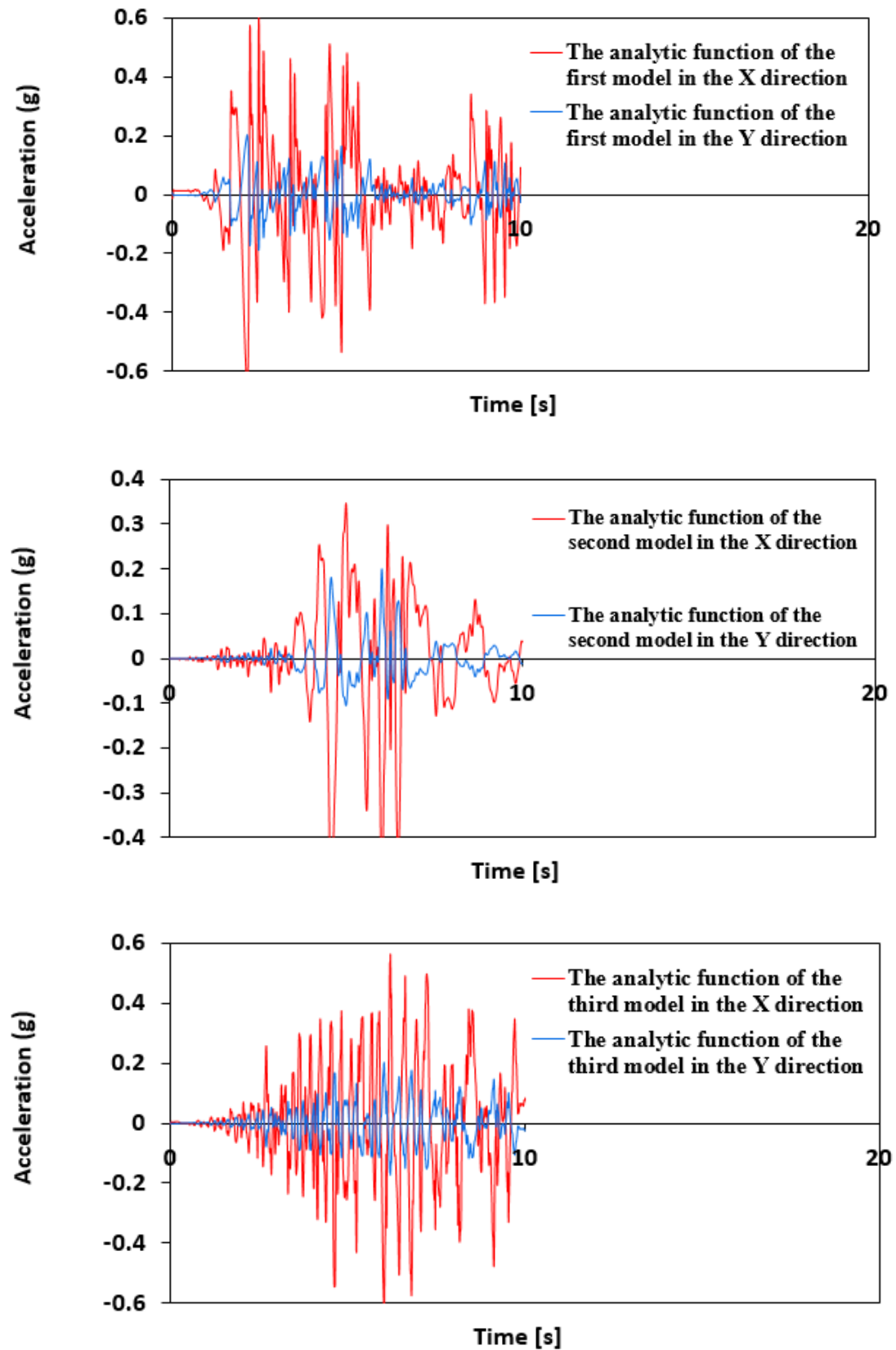


Figure 6. Analytic Functions in X and Y direction

4. Analyze the Results

In this section, three modeling models in ABAQUS software were analyzed .once under the records of three selected dynamic time history earthquakes analysis and then the same structures using the durability analysis method analyzed and finally the results of the two methods are compared. Figures 7 to 13 show the comparison of the results of analyzes.

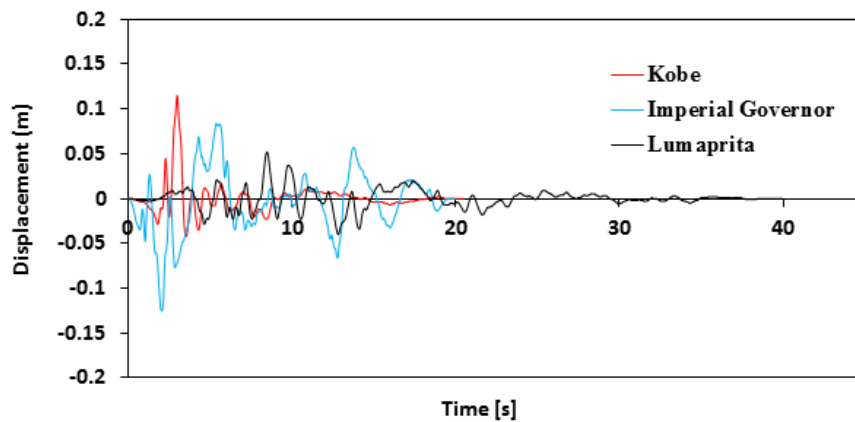


Figure 7. Comparison of the displacement values of the 5th floor structure under earthquake types by analyzing time histories

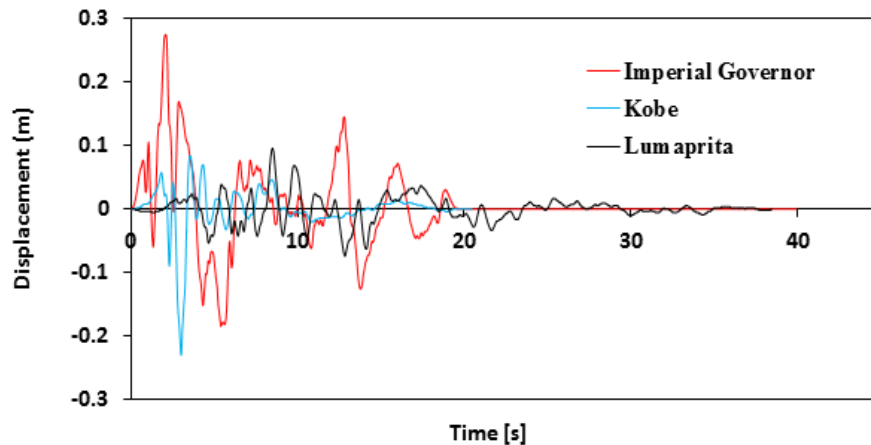


Figure 8. Comparison of the displacement values of the 5th floor structure under various analytical functions of durability

According to Figures 7 and 8 In the Kobe earthquake record, the amount of displacement in the first seconds of the durability analysis functions was greater than the time history analysis method and in the conditions of structures with bending frames did not cause problems and the analysis of the durability method versus the history analysis works best to damp the record and react to the structure and holds the structure in the base of the 5th floor for a more time, and this is an advantage of durability analysis method.

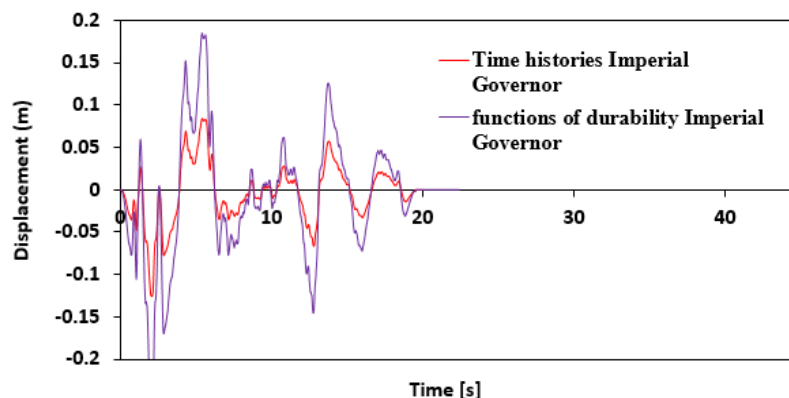


Figure 9. Comparison of the displacement values of the 5th floor structure under the analytic functions of durability and analysis of time histories for Imperial Governor Record

As shown in Figure 9, according to the desired domain the durability analysis method in comparison with the time history method has the larger displacements (25 percent) and this increase from the structural aspects will be considered by the designer which can be related to the type of earthquake, and the designer chooses the method for each constructed construction.

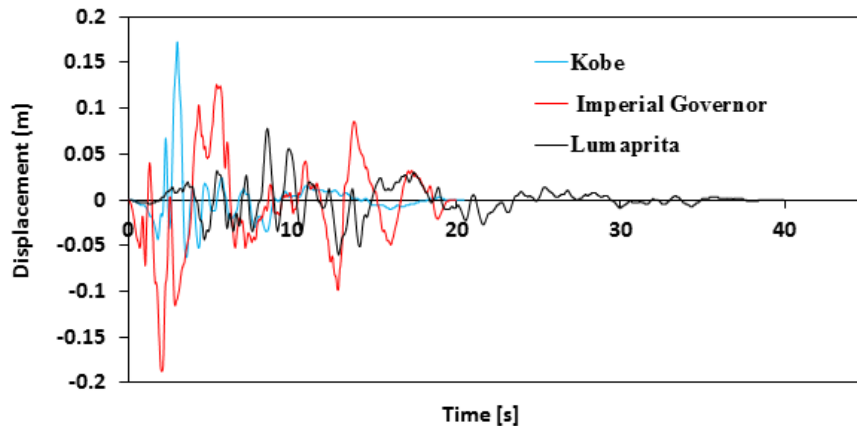


Figure 10. Comparison of the displacement values of the 10th floor structure under earthquake types by analyzing the time history

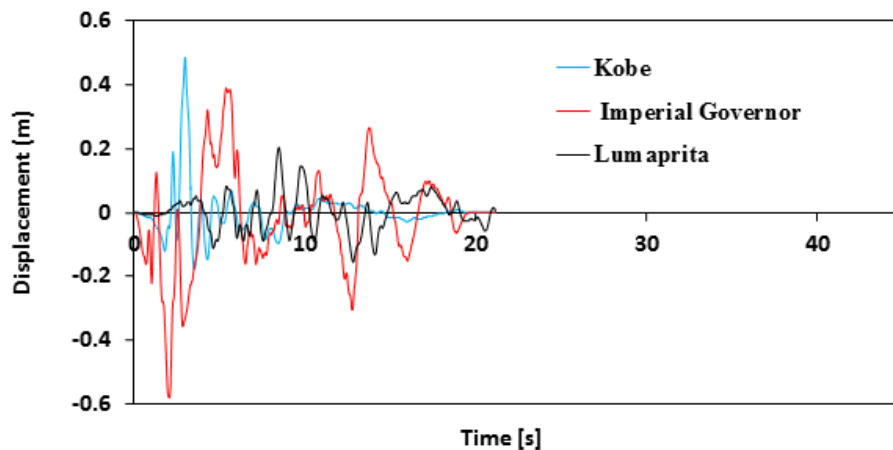


Figure 11. Comparison of the displacement values of the 10th floor structure under various analytical functions of durability

According to the comparison of Figures 10 and 11, it is important to note that in the 10th floor structure for the Kobe earthquake record, the displacement of the durability time method is approximately twice of the time history method, and this happens at the initial time of 7 to 10 seconds. In the initial times for the lumaprita earthquake record, from the 20th second, displacement amount in the durability analysis function significantly reached to zero, while in the time history method this displacement continued to almost 40th second, and the reason of this sharp difference was increase the number of floors. It is worth noting that from 15 to 20 percent of building heights in the analysis parameters of the durability time method displacement amount was not significant and in higher times, due to the structural strength and the passing of the high-risk modes of the structure, the amount of that are neglected in equations of this method.

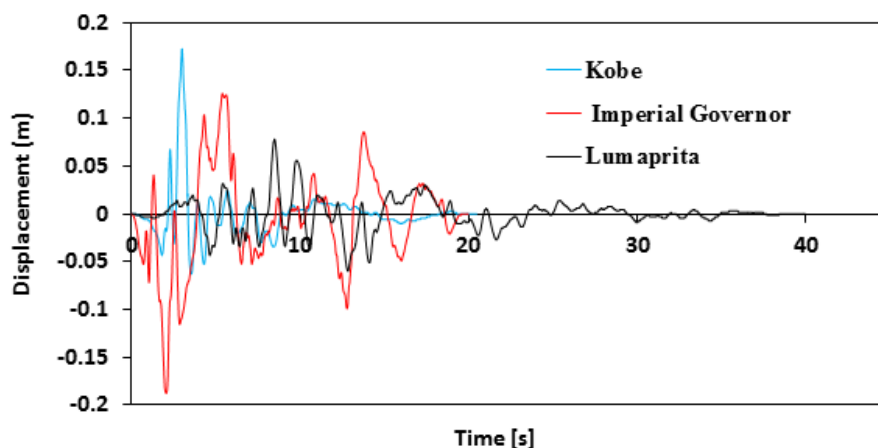


Figure 12. Comparison of the displacement values of the 15th floor structures under earthquake types by analyzing time histories

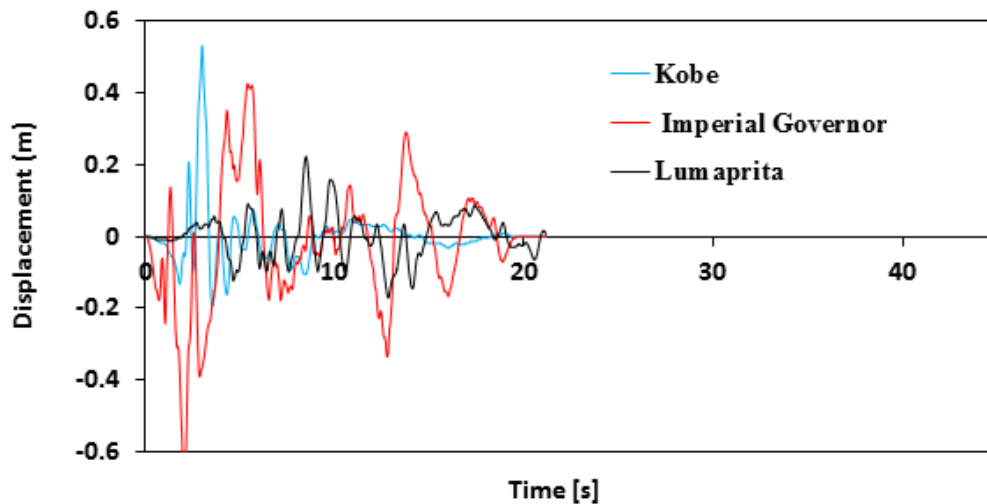


Figure 13. Comparison of the displacement values of the 15th floor structure under various analytical functions of durability

By using 15th floor structure figures that mentioned above it is observed that with structural considerations that are used by the designer in the regulations, durability time method can be used for tall buildings. Of course it should be noted that according to selected earthquake record, the desired displacements of the structure be put further verified with the software and for further floors be measured the ABAQUS output.

5. Conclusions

In this study, steel folding frameworks with 5, 10, and 15 floors were investigated under two analytical methods by finite element software ABAQUS. Initially, the structures were studied under three types of Imperial Valley, Kobe and Lumaprita earthquakes, along with gravity loading using time history analysis, then examined the behavior of the studied structures by durability analysis and finally the solutions were compared to each other. The results in this research are as follows:

- Although the Kobe record has exceeded the displacement values for the time history method, but in the durability analysis method, it is lower than the other two records, and it can be said that the durability analysis method for earthquakes with higher intensity and time is more efficient, and for the Time-less earthquakes by time history method Parametrically have a parametrical difference of 5%.
- According to the results of the method of durability analysis, the presence of low-frequency earthquake records requires more modelling in parametric conditions and, in comparison with the time history method, we need to study more detailed modelling of the parameters considered by the previous investigators.
- Time durability method analysis is based on time-history, thus preserving the sign of all forces and displacements. This can be considered as an advantage over traditional response spectrum analysis where the signs of forces are not preserved, resulting in some unwanted over-design in the design phase.
- The stresses in the structures increase with increasing levels.
- The displacement values in the structures increase with increasing classes. This ratio is observed in both methods. However, there are some errors in the durability of the values.
- The displacement values in the structures increase with increasing loading values. The precision of the two methods is remarkable in this case.
- The speed of analysis in the continuous analysis method is much higher than the analysis of time histories.
- The accuracy of the results in the method of durability analysis is less than the time history analysis method. But due to the differences in the low values in the results, and on the other hand, the speed of analysis can be a good and suitable alternative method for structural analysis.

6. Conflicts of Interest

The author declares no conflicts of interest.

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