Port Said Engineering Research Journal
Faculty of Engineering - Port Said University
Volume (28) No. 4 pp: 1:14

# Field Assessment of Fundamental Periods for Typical RC Buildings in Port Said Using Ambient Vibration Testing

*Moataz El-Rayes [1] *, Emad Yehia Abdel-Galil [2], Ezzaat Ahmed Sallam [3]*

[1] *Civil Engineering Department, Faculty of Engineering, Port Said University, Email: moataz.elrayes@eng.psu.edu.eg*
[2] *Civil Engineering Department, Faculty of Engineering, Port Said University, Email: emad0057@eng.psu.edu.eg,*
[3] *Civil Engineering Department, Faculty of Engineering, Port Said University, Email: ezzat.sallam@eng.psu.edu.eg,*
**Corresponding author, DOI: 10.21608/PSERJ.2024.301020.1347.*

*Received 2-7-2024*
*Revised 4-9-2024*
*Accepted 8-9-2024*

## ABSTRACT

Operational modal analysis (OMA) is one of the most intriguing engineering fields nowadays, which ordains in the studies of modal parameters of existing small buildings under operational forces. The estimation of fundamental natural period is usually acquired from code equations which are of empirical nature, hence, the problem arises. An In-field study must be performed to acquire the fundamental period of existing structures, hence, compare the results with code equations to show the discrepancy in results. This study aims to experimentally validate the modal parameters acquired using accelerometers by comparing them with those measured using code equations and finite element method (FEM). Numerical methods such as Fourier transform, peak picking, and the frequency domain decomposition (FDD) technique were used for modal parameters extraction and validation. In addition, finite element modeling of the existing structure, including support flexibility, was investigated. The studied structures include six case studies ranged in height from five to twelve stories buildings. The structural system includes moment resisting frames (MRF) and shear wall moment resisting frames (SWMRF) resting on raft foundation. The experimental results showed that the natural frequencies obtained showed discrepancies between infield results and code equation that reached 200% in some cases. Finally, a novel method for estimating the fundamental natural period was derived using field measurements. The validity of the proposed formula paves the way for more effective identification for the fundamental natural period for moment resisting frame structures.

**Keywords**: Operational Modal Analysis, Fundamental Period, Ambient Vibration, Regression analysis.

## 1 INTRODUCTION

Since the last century, Structural resistance to wind and other lateral loads has been increasingly emphasized in building codes for tall buildings in Egypt. This means that building codes incorporated seismic provisions that will increase the lateral design loads for many tall buildings. Many high-rise structures in Port-Said (subject of the paper) are residential, especially in the upper stories. Architectural constraints in high-rise apartment buildings preclude the prevalent usage of shear walls to resist lateral forces. Consequently, in order to enhance their lateral resistance, several buildings have been incorporated which rely upon their frame action (four case studies). In the structures studied herein, the framing system is designed to resist a considerable portion of the lateral load, the remainder of which is carried by columns or shear walls interacting with the frame. The base shear resistance of the structure is given as a function of the building's first natural period, which is derived in most existing codes for seismically active regions of the country. Although codes give a simplified equation to estimate the fundamental natural period at its ultimate capacity, the values acquired based on the actual building dynamic properties at both service and limit state levels may differ considerably [1]. Furthermore, the Egyptian code [2] gave a guideline in which structural engineer may use numerical methods to acquire the fundamental period and these values acquired should not exceed the values given using the empirical equation by 20%. That where the problem arises, the values acquired using numerical methods gave values that exceeds in some cases twice (200%) the values given by the empirical equation. These huge differences presented the necessity for modifying the code equation as would be shown later on in this paper. Furthermore, the implementation of the new refined equation could significantly reduce the design forces for building above seven stories which paves the way for more economic building's design. Past researches showed that field modal testing is a proper way for finding out the fundamental period. The scale of these structures virtually precludes forced response experiments and traditional modal analysis. Nonetheless, ambient vibrations are very informative and have certain advantages [1]. The best technique for both the determination of period and associated damping is to identify the vibration mode shapes which can only be achieved if two or more synchronized sensors can record the motion at different locations in the building. However, for determining just the fundamental period, a single instrument located at the top of the building can, in most cases, accurately determine that period [3].

Goel [4] gave an estimation of the fundamental natural period of shear wall reinforced concrete buildings. Firstly, a database including vibration periods for buildings measured from their recorded motion during past California earthquakes was used, then an empirical equation by calibrating a theoretical equation derived using Dunkerley's method was developed. Then a comparison between the periods obtained from this equation to the measured data through regression analyses was made.

Goel [4] concluded that even though regression analyses of the available database of vibration period previously recorded from past earthquakes have led to the development of the derived equation for assessing the natural period of the investigated buildings, more research must be done for more buildings that is not included in the study once their vibration data will be recorded or an earthquake data becomes available.

Crowley [5] stated that estimation of fundamental natural periods of RC buildings based on its height is not an ingenious concept. The research focused on these relationships provided by many design codes that have been developed for force-based design and so gives conservatively prediction for the base shear force, as natural periods are usually underestimated. Moreover, it was concluded that most of the European structures constructed before the introduction of capacity design principles in seismic regulations, found to give overestimation of periods of vibrations than their modern equals. Also, it used analytical procedures to obtain the yield natural period of some buildings with various heights included in the study such as (Eigen value where the structure is represented as a multi degree of freedom MDOF system to obtain its natural frequency and pushover analysis), due to their increased resilience and the lack of measured period using devices for the European buildings.

Waleed [6] performed a nonlinear lateral analysis of masonry infilled reinforced concrete buildings through an analytical approach. A modal example of buildings was made and divided them into two categories, the first one was moment-resisting frames and the second one was shear wall moment-resisting frames buildings. Many parameters of masonry infilled walls such as opening sizes, wall thickness, and the existence of infilled walls on the ground floor were taken into consideration. Then the interaction between the infilled walls, RC shear walls with different heights and also for different floor numbers ranging from six to twenty stories buildings was modeled by considering the behavior of infilled walls as an equivalent strut.

The research conclusion was, the contribution of the infilled walls to the lateral response of buildings should not be overlooked, as it can drastically change the lateral response of RC framed buildings by increasing the total mass and stiffness of the buildings which can change the estimation of its natural period, hence affect the total base shear force calculated.

Chalah [7] suggested an equation for the determination of the fundamental period of shear wall buildings. Even though most of the work done in this field was done by analyzing experimental works obtained from ambient vibration. A theoretical point of view based on solving differential equations was approached; with assumptions on the vibration modes. Chalah [7] concluded that Fundamental natural period obtained by experimental measurements from ambient vibrations and mathematical equations was developed by statistical treatment and took into account the geometrical characteristics of the buildings with no regard for shear wall repartition. Consequently, the study was approached from Dunkerley's equation using assumptions on constant height and mass, the result has shown that a more realistic equation is developed and it is expressed in terms of mechanical, geometrical characteristics and number of floors of the shear wall buildings.

This research is concerned with some points that need further investigation. Firstly, Assessing the contribution of beam slab, shear walls and coupling beams to the overall lateral stiffness in several MRF and SWMRF buildings. Secondly, comparing the building's compliance with current and proposed Egyptian design code for wind and seismic forces respectively. Thirdly, comparing the natural periods of structures under construction to their code prescribed periods after some wind storms (in-operation forces). Model the measured buildings in their "as-built" condition using state-of-the-art software not available to the design team at the time the structures were designed (i.e. old buildings are measured during In-situ measurements). Fourthly, deriving a new proposed equation for estimating the fundamental natural period based on ambient vibrations results carried out during in-Situ study. Finally, the results obtained through the study are discussed, and the main conclusions are given.

# 2 INFIELD STUDY

## 2.1 Procedure of Measuring Ambient Vibrations of RC Buildings

Acquiring acceleration records by placing the accelerometer at different places at the intended structure to be measured during strong wind, hence, deducing the structural response in a form of acceleration records which can amplify the mode shapes of the signal. In consequence, the recorded signal will reflect the mode shapes of the intended measured structure. this can be done by following the next steps:

a) Developing parameter estimation software for the analysis of ambient vibration measurements from large-scale structural systems. The software is done in MATLAB [8] to convert the signal acquired in the time domain into the frequency domain by a transfer function in our case (Fourier transform) then it computes auto-power spectra and phase spectra between a "measurement" or "response" sensor and a "reference" sensor. The response sensor was placed at the roof level and the reference sensor was placed at a level near the ground.
b) Verifying the results from the programs developed in step-1 with a parallel but independently developed routine, then verifying the computations with small-scale tests on laboratory models [9]**.**
c) Comparing experimentally estimated periods with periods computed in (a parallel study) by finite element modeling of the "as-built" structure. As mentioned earlier, the code equation relies on height which gives an empirical value, while modelling the structure can represent the real mass and stiffness of the structure. Ultimately, one can recalibrate the structural coefficient (Ct) for a more reliable equation.
d) Establishing a set of base-line parameters for comparison with future testing during different wind conditions.

## 2.2 Derivation of Proposed Equation

In order to perform regression analysis and derive an equation for estimating the fundamental natural period based on building height, several buildings were measured using two devices; a 3-axis accelerometer along with a mobile sensor.

The long-range objectives are to:

a) Assess the actual contribution of beam slab, shear walls and coupling beams to the overall lateral stiffness in several reinforced concrete structures.

b) Compare the building's compliance with current Egypt design codes and proposed equation for wind and seismic forces respectively.

c) Compare the natural periods of structures under construction to their periods after some wind storms to try to differentiate the good readings from faulty ones. Model the measured buildings in their "as-built" condition using state-of-the-art software[10] [11] not available to the design team at the time the structures were designed. Investigate the influence of partitions and cladding on the building's response to lateral loads.

d) Investigate the influence of foundations and soil conditions on the measured building response at different periods by representing the foundation in the modelling process and taking the effect of soil by assigning subgrade reaction rather than fixed supports.

## 3 DESCIRPTION OF THE TESTED BUILDINGS

The following list includes the buildings that were measured, Table 1.

**Table 1. Case studies for investigated high-rise building**

| Building No. | No of stories | Building Height | Structural system |
|---|---|---|---|
| **Case study-1 Ganna** | 12 story | 37 m | Frames + Shear walls |
| **Case study-2 Jazaer** | 12 story | 36 m | Frames + Shear walls |
| **Case study-3 Assaf** | 6 story | 20 m | Ductile frames (beams+slabs) |
| **Case study-4 Diaa** | 6 story | 20 m | Ductile frames (beams+slabs) |
| **Case study-5 Sharawy** | 7 story | 23 m | Ductile frames (beams+slabs) |
| **Case study-6 Ahrar** | 10 story | 31 m | Ductile frames (beams+slabs) |

The following map is marked with the designated case studies at their real locations, Figure 1.

**Figure 1: Locations of the investigated case studies.**

The following List shows which building was available for modelling based on the availability of the drawings Table 2.

**Table 2. list of buildings with available drawings**

| Building No. | FE Modelling | Ambient Tests | Drawings |
|---|---|---|---|
| **Case study-1 - Ganna** | √ | √ | √ |
| **Case study-2 - Jazaer** | √ | √ | √ |
| **Case study-3 - Assaf** | √ | √ | √ |
| **Case study-4 - Diaa** | √ | √ | √ |
| **Case study-5 - Sharawy** | X | √ | X |
| **Case study-6 - Ahrar** | X | √ | X |

The following figure shows a real time picture of ganna tower Figure 2.

**Figure 2: Real time picture of Ganna Tower**

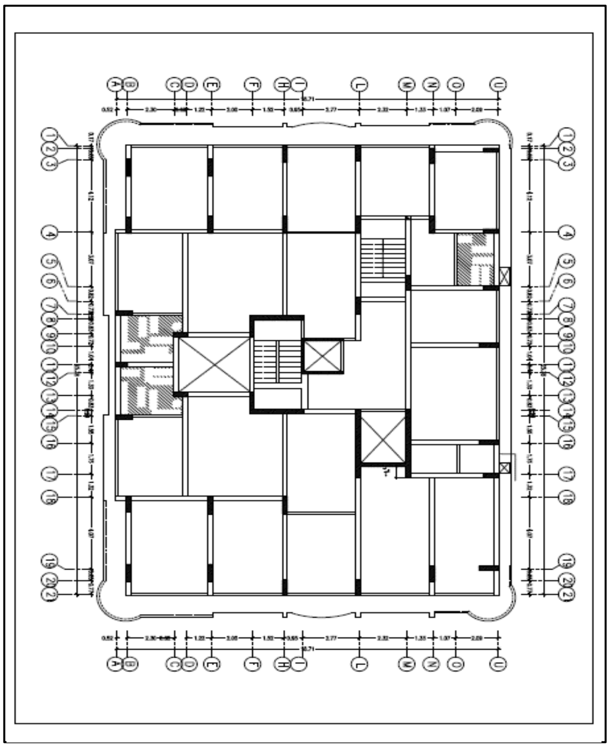

**Figure 3: Typical floor plan for Ganna tower and its structural system**

### 3.1 Case Studies Geometry

The case studies ranged from 6-story to 12-story. In total, there were six case studies that were measured. Firstly, Ganna tower was measured. The building consists of a 12-story high-rise building and located next to the Mediterranean Sea in Port-Said, Egypt. This residential building was completed in 2006, and it has a reinforced shear wall at the center of the building and several columns located internally and along the perimeter **Figure 2 &3.** Secondly, Jazaer tower was measured. The building consists of a 12-story high-rise building and located next to the Suez- Canal in Port Fouad - Port-Said, Egypt. This residential building was completed in 2011, and it is a reinforced concrete (RC) structure. It consists of core walls located at the center of the building and several columns located internally and along the perimeter. The floors were solid slabs of 120 mm in thickness. The beams sections were 120 mm by 600 mm. The remaining two case studies were moment resisting frames with beams of size 120 mm by 600 mm and slab sizes ranges from 120 to 140mm.

### 3.2 Effect of Cracking

The effect of cracking was considered according to the code requirements [2]. For floors and beams, a study was made to assess the applied load and the section capacity to assess whether the section is cracked or not. The dynamic characteristics of the building were acquired from the existing structure to investigate the influence of nonstructural elements on modal characteristics along with the effect of the soil.

### 3.3 Model Updating

A final step in this investigation was to model the building mathematically and calibrate the model's geometric and material properties to correspond to the results obtained from the field measurements [12]. Ambient vibrations measurements were taken while the structure was in operation which means that all the architectural components were in place. The wind speed was 33 Km/hr [13] at the time of the measurements during February 2021.

### 3.4 Soil effect

The subgrade reaction was taken according to the soil report and it ranged from (11000 to 12500) KN/m2/m. The foundation was represented as a shell element and the thickness ranged from (600 to 1100) mm (Elastic supports). the transitional movement were prevented in x and y direction and was allowed in the direction of the soil (z direction).

## 4 FEM RESULTS

The investigated structures were modelled using ETABS V17 [11]. Slabs were modeled as shell element, columns as frame element and the core wall as shell element each with its own size and material. A comparison and review of element's size and material were made between design stage assumptions and in-situ tests Figure 4 &5. Finally, each element was modelled as it was constructed to get the best result possible. Iterations needed to be done to have a true representation of the structure in reality. In other words, to match the results from field measurements to the results obtained from modelling (Model updating) [12] (for example the results from elastic supports were a better match than fixed supports). In addition to the right representation of the structure, the modulus of elasticity was properly considered for the concrete as well as for the masonry. The non-structural elements were modelled as a one-direction strut (compression strut) [6].The thickness of the strut was acquired using FEMA 365,

$$a = 0.175\,(\lambda\, I\, h_{COL})^{-0.4}\, r_{inf}$$

Eq. (1)

$$\text{Where } \lambda_i = \left( {E_{me} t_{inf} \sin(2\theta)} \Big/ {4 E_c I_{col} h_{inf}} \right)$$

Eq.(2)

$h_{col}$ = column height between centerlines of beam.
$h_{inf}$ = height of infill panel.
$E_{fe}$ = expected modulus of elasticity of frame material
$E_{me}$ = Expected modulus of elasticity of infill material
$I_{col}$ = moment of inertia of column
$L_{inf}$ = length of infill panel
$r_{inf}$ = diagonal length of infill panel.
$t_{inf}$ = Thickness of infill panel

The structural and architectural plans were made available. Modelling the floor system, columns and core walls was straight forward. In addition, the foundation, soil effect, and masonry infill (MI) were taken into consideration. The soil and foundation were modeled as a shell element and springs. The results were as follows

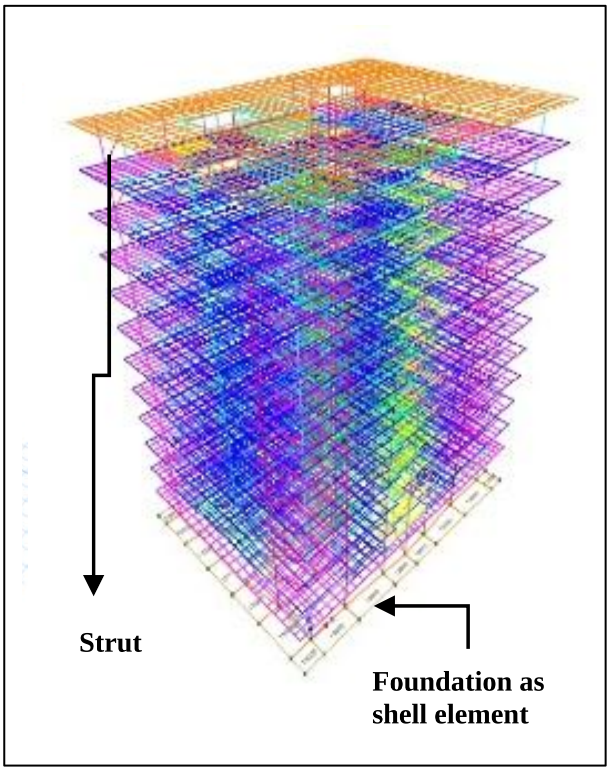

**Figure 4: Modeling of Ganna Tower using ETABS V17** [11] **(Elastic supports)**

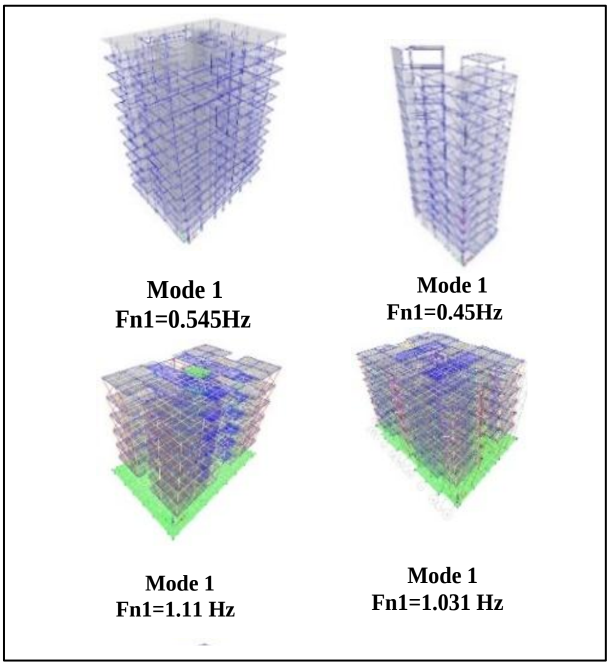

**Figure 5: Fundamental frequencies of Available case studies using Etabs V17 [11] (Elastic support).**

## 5 AMBIENT VIBRATION TESTS

The concept behind these measurements is that in-operation forces (wind forces) will be imposed upon the structure causing some deformation, the objective is to try to catch the structural response in form of acceleration records and employing the previous methods (Peak-Picking and FDD) in order to identify the fundamental frequencies. As proved earlier using the laboratory model, modal parameters could be extracted during in-operation forces using the same accelerometers [9].

### 5.1 Buildings Plans

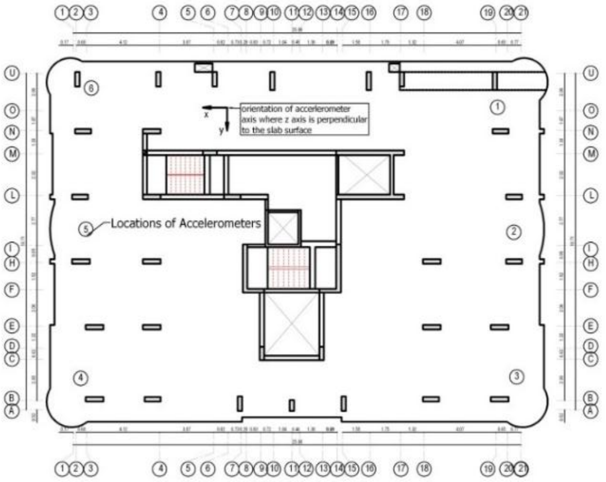

**Figure 6: Roof- plan of four case studies with the locations of accelerometer**

### 5.2 Ambient Vibrations Records

The accelerometer was placed at six different locations as shown in, Figure 6. The measurements were taken during 8 hours at different days and weather conditions. The sampling rate was 20 Hz and the axis of the accelerometer was in the same direction at all times. The maximum acceleration at any point was not exceeding (0.3 $cm/s^2$) Figure 7. The length of the records was big enough to use 4096 sample points which allowed us to choose a small sampling frequency of (0.00488 Hz) which will reduce errors in spectrum estimation. The Fourier transform was applied to the records, and the results are shown in Figure 8.

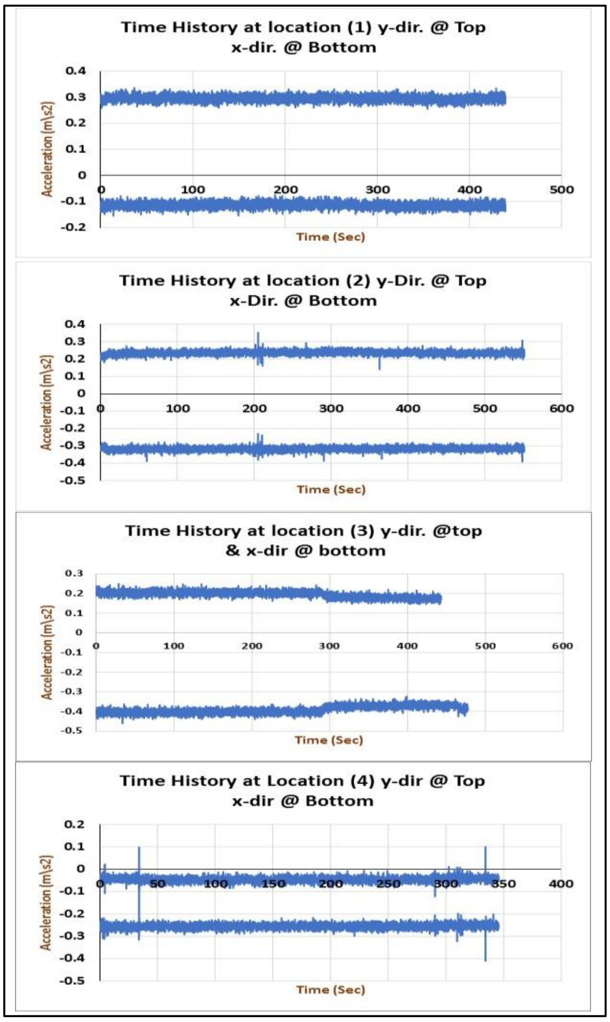

**Figure 7: Acceleration records at various locations in both direction x and y for Ganna Tower**

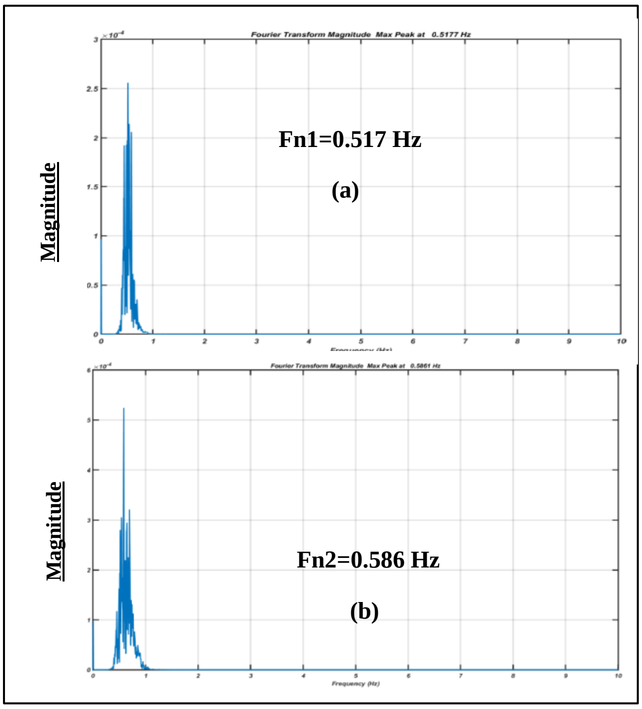

**Figure 8: (a) Spectrum for Ganna Tower after filtering at south west corner of the building, sensor location No.6 in x-direction showing first mode. & (b)sensor location No.4 in y-direction showing second mode.**

For the second case study Jazaer tower, the sensor's locations were carefully placed, in the sense of matching the intended mode shapes. The building was a slender building with no surrounding buildings which meant that no disturbance in the spectrum will happen (torsional unexpected modes) Figure 9 to 11.

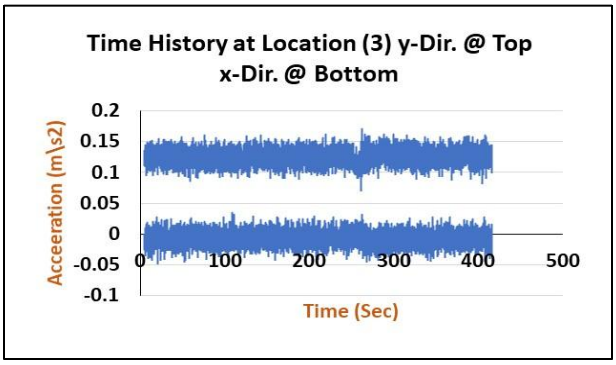

**Figure 9: Acceleration records at various locations in both direction x and y for Jazaer Tower**

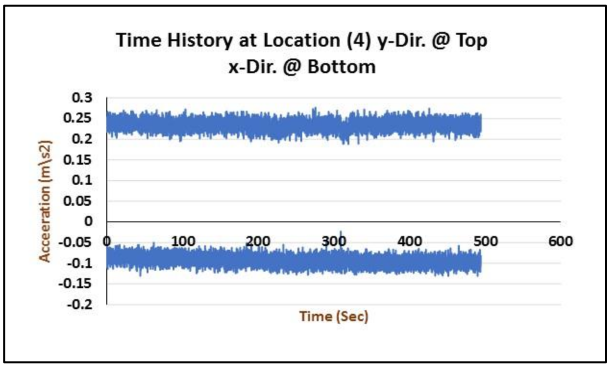

Figure 10: Acceleration records at various locations in both direction x and y for Jazaer Tower

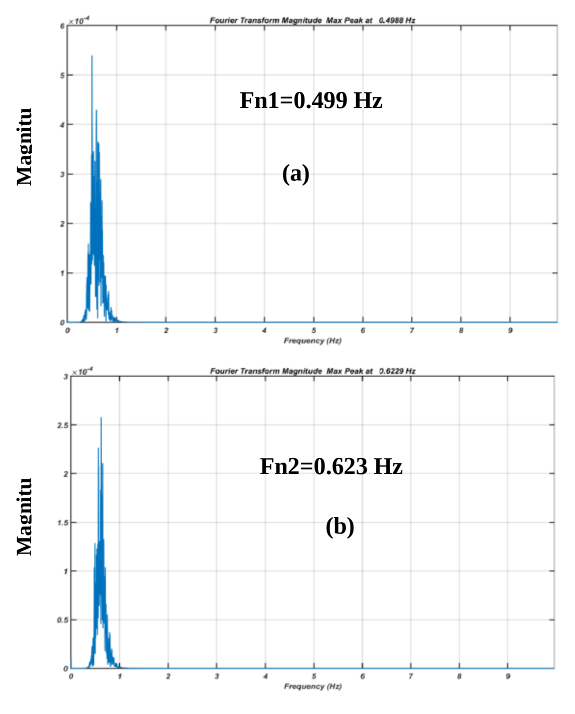

Figure 11: (a) Spectrum for Jazaer Tower after applying band pass filter. at south west corner of the building, sensor location No.1 in x direction showing mode 1 (b) At location North west sensor location No.2 at y-direction showing mode 2

The accelerometer was placed at four different locations and measurements were taken as shown in, Figure 12 & 13. The measurements were taken during a period of 8 hours per trial. The building was vacant during testing which meant that several floors could be accessible for measurements. Several combinations of measurements were taken for optimum extraction of the modal parameters. Firstly, the sensors were placed at both roofs. Secondly, the sensors were placed at certain floors and compared to the roof floor.

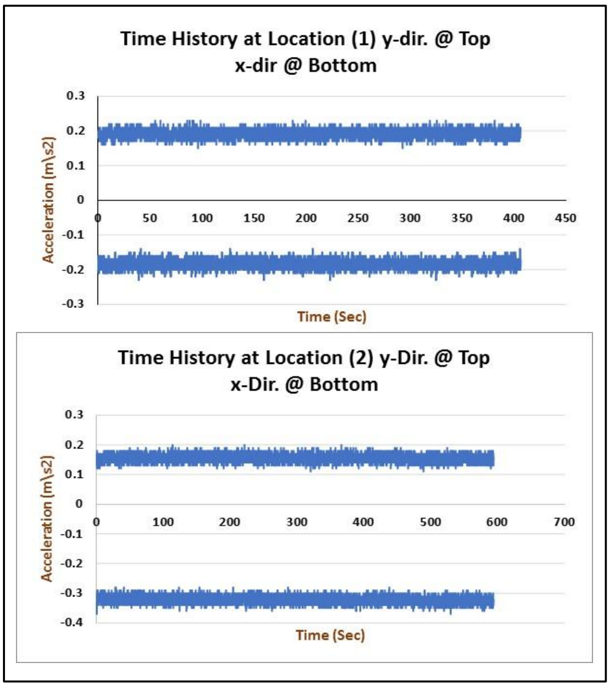

Figure 12: Acceleration records at various locations in both direction x and y for Assaf building

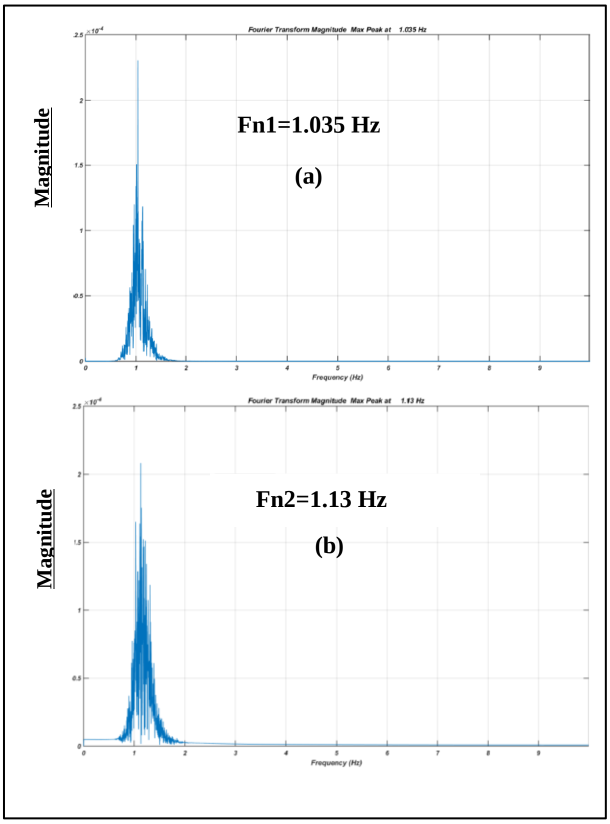

Figure 13: (a) Spectrum for Assaf building after applying band pass filter. at North west corner of the building, sensor location No.4 in x direction showing mode 1 (b) At south west corner of the building, sensor location No.2 at y-direction showing mode 2

The same procedure was performed for the rest of the case studies as follows Figure 14 to 19.

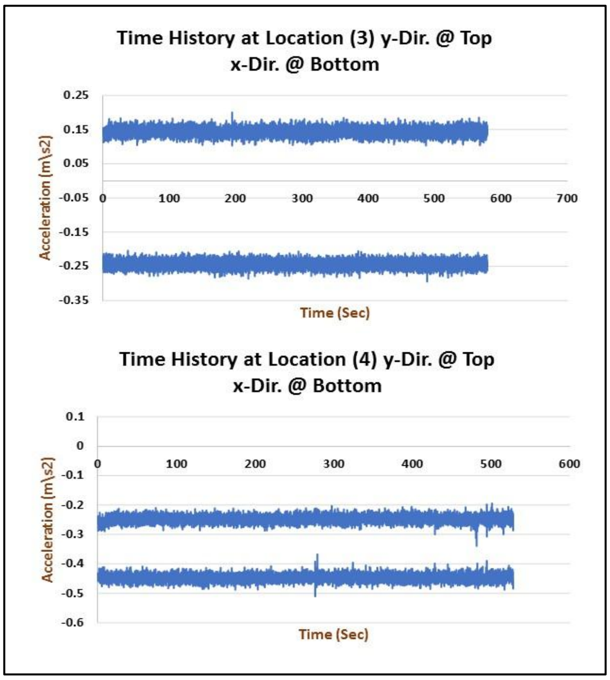

**Figure 14: Acceleration records at various locations in both direction x and y for Diaa Building**

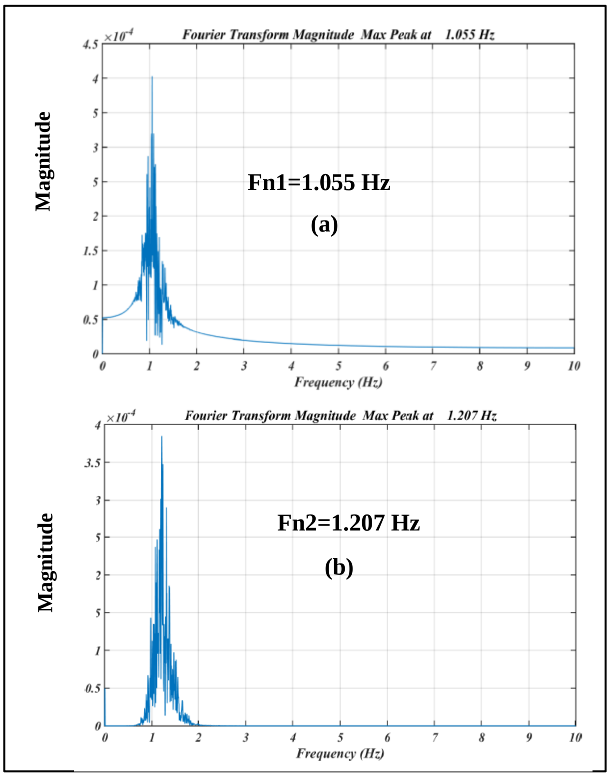

**Figure 15: Spectrum for Diaa Building after applying band pass filter, at south east corner of the building, sensor location No.1 in x direction showing mode 1**

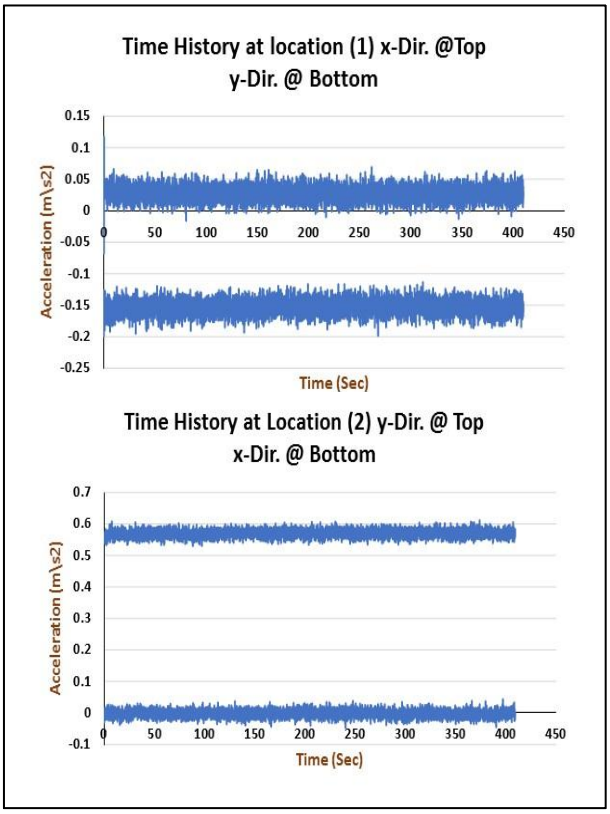

**Figure 16: Acceleration records at various locations in both direction x and y for sharawy building**

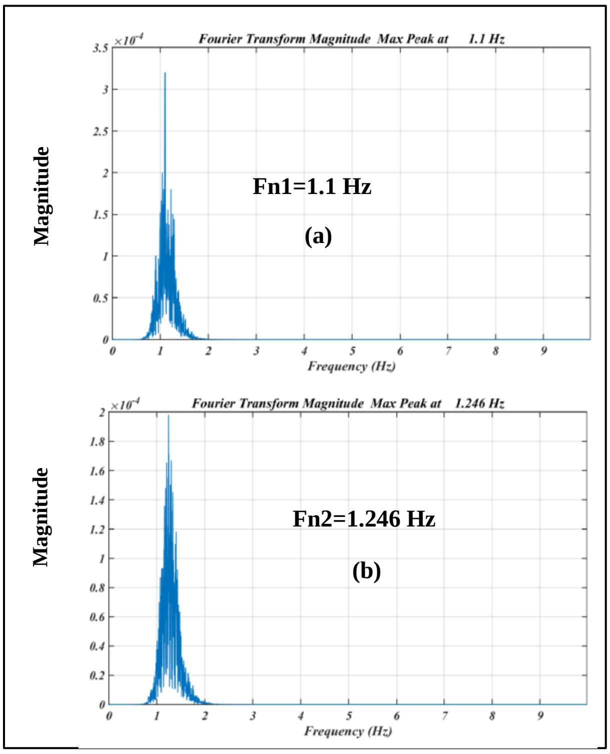

**Figure 17 :(a) Spectrum for sharawy Tower after applying band pass filter, at south west corner showing mode 1 (b)At location North west showing mode 2**

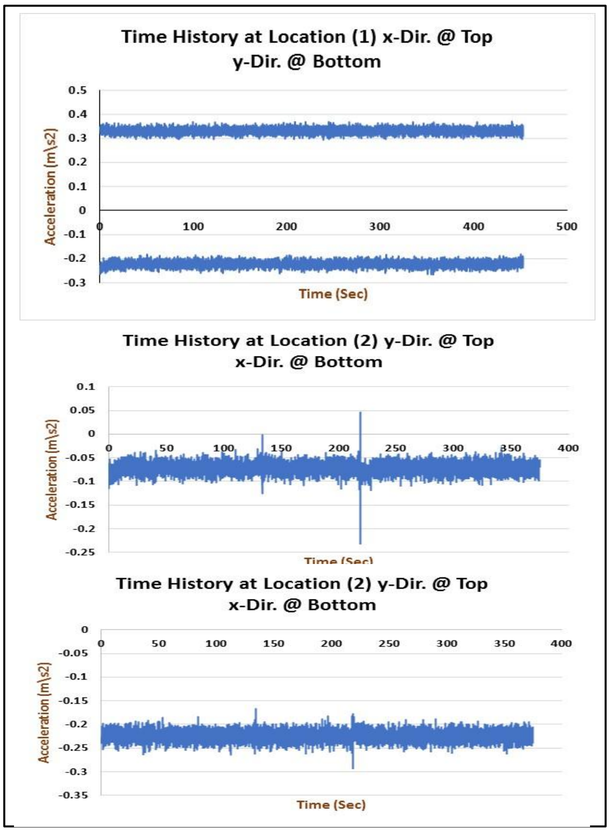

**Figure 18: Acceleration records at various locations in both direction x and y for Ahrar building**

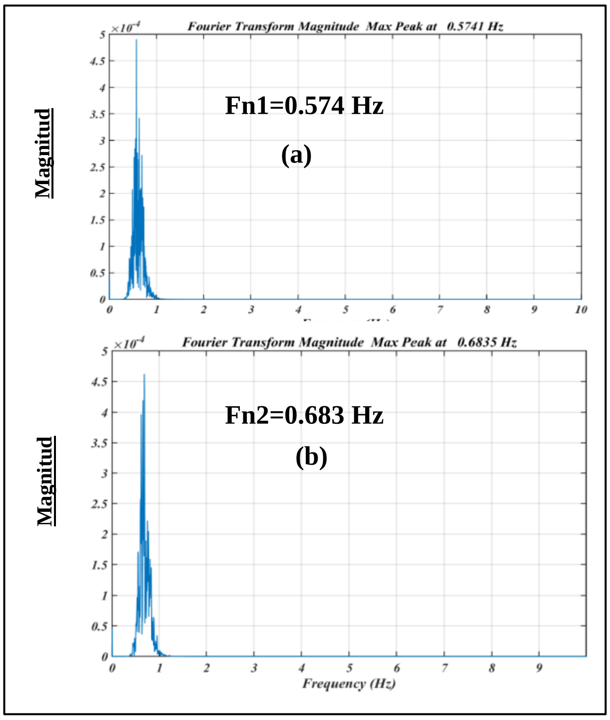

**Figure 19: (a) Spectrum for Ahrar Tower after applying band pass filter, at south west corner of the building, sensor location No.1 in x direction showing mode 1 *(b) At location North west sensor location No.2 at y-direction showing mode.***

# 6 DISSCUSSIONS OF RESULTS

## 6.1 In Field Study Results

For several case studies, since several measurements were made along the whole perimeter of the structure, the first transitional modes were clearly shown in the spectrum. The modes were consistently clear in most of the measurements. The baseline for comparison were the modal parameters extracted using FEM results while taking the masonry infill, soil and foundation effect table 3 & figure 20.

**Table 3. comparison of results obtained during in-situ measurements between FEM and Accelerometer (Ganna Tower)**

| Device<br>Mode | FEM<br>(Hz) | Accelerometer<br>(Hz) | Difference<br>(%) |
|---|---|---|---|
| **Mode 1** | 0.515 | 0.513 | 1.0% |
| **Mode 2** | 0.610 | 0.586 | 4.0% |

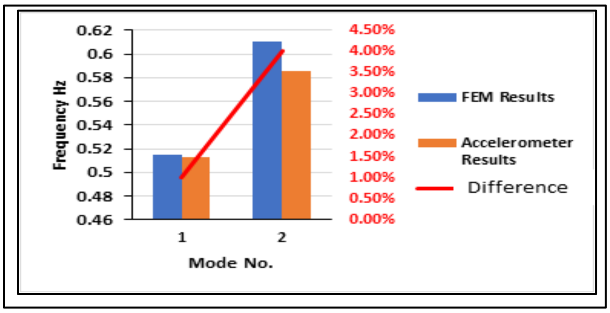

**Figure 20: Difference display taken during In-situ measurements between FEM and accelerometer for Ganna-Tower.**

The following chart illustrates the relationship difference between fundamental frequencies (i.e 1st and 2nd mode) for analytical and mathematical method. As clearly seen, the error reduces significantly for the 2nd mode, that could be attributed to the fact that the structure had a very small breadth. The previous reason made the amplitude of shaking of that direction (minor axis) high enough to get a better spectrum resolution table 4 & figure 21.

**Table 4. comparison of results obtained during In-situ measurements between FEM and Accelerometer (Jazaer Tower)**

| Device<br>Mode | FEM<br>(Hz) | Accelerometer<br>(Hz) | Difference<br>(%) |
|---|---|---|---|
| **Mode 1** | 0.450 | 0.499 | 8.88% |
| **Mode 2** | 0.610 | 0.623 | 3.0% |

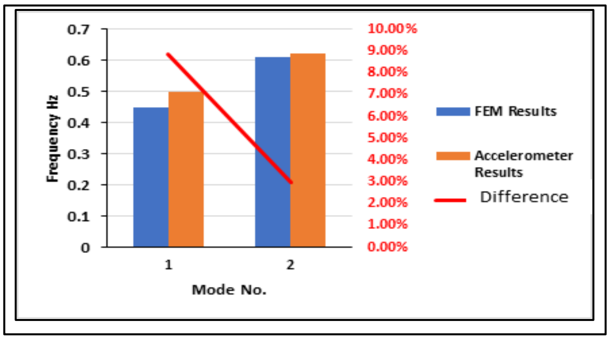

**Figure 21: Difference display taken during In-situ measurements between FEM and accelerometer for Jazaer-Tower.**

As clearly seen from the following chart, the error in results between analytical and mathematical results was very small and it reduces transitioning from 1st to 2nd mode. But overall the error did not exceed 7.24% table 5 & figure 22.

**Table 5. Comparison of results obtained during In-situ measurements between FEM and Accelerometer (Assaf Building)**

| Device<br>Mode | FEM | Accelerometer | Difference % |
|---|---|---|---|
| **Mode 1** | 1.110 | 1.035 | 7.24% |
| **Mode 2** | 1.202 | 1.130 | 6.20% |

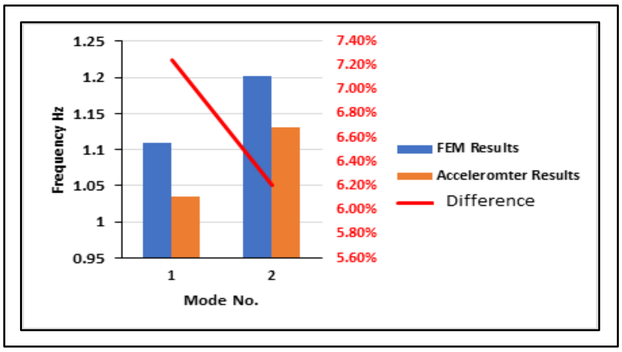

**Figure 22: Comparison for results obtained during In-situ measurements between FEM and Accelerometer, for (Assaf building).**

As clearly seen from the following chart, the error in results between analytical and mathematical results was very small and it reduces transitioning from 2nd to 1st mode. But overall, the error did not exceed 5.87%.

The two cases (5 and 6) had no drawings available but their results were needed for completing the regression analysis. Using the accelerometer readings only the analysis was performed, which means the input time history was analyzed and the modal parameters were extracted using the peak picking method table 6 & figure 23.

**Table 6. Comparison of results obtained during In-situ measurements between FEM and Accelerometer (Diaa Building)**

| Device<br>Mode | FEM | Accelerometer | Difference |
|---|---|---|---|
| **Mode 1** | 1.031 | 1.055 | 2.30% |
| **Mode 2** | 1.140 | 1.207 | 5.87% |

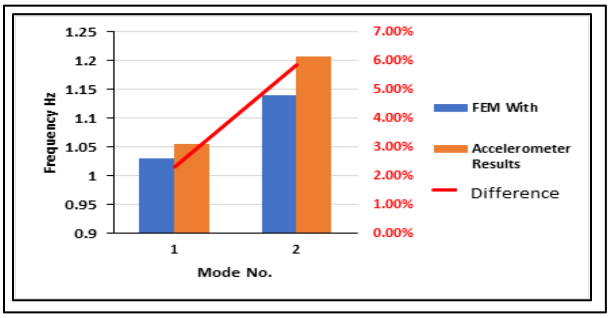

**Figure 23: Comparison for results obtained during In-situ measurements between FEM and Accelerometer, for (Diaa building).**

## 6.1 Assessment of Code Equations

According to ECP-201, the code equation for estimating the fundamental natural period of the building is as follows:

$$T = C_t H^{0.75} \qquad \text{Eq.3}$$

Where,

$C_t$ = *structural parameter*

$C_t = 0.05$ *where the building having columns resisting horizontal loads*

$C_t = 0.075$ *where the building having both columns plus shear walls resisting horizontal loading.*

*H = building Height in meters.*

Based on the extracted frequencies from in-situ measurements, a new proposed equation can be derived using regression analysis. The code equation is also shown for comparison as follows table 7:

**Table 7 comparison between results obtained during In-situ measurements before applying the proposed equation**

| No. of Floors | Structural System | Height (m) | Code Eq. | Ambient Vibrations | | FEM |
|---|---|---|---|---|---|---|
| | | | $T = C_t H^{0.75}$ | Freq | T | Period |
| | | | $C_t = 0.075$ | Hz | Sec | Sec |
| **Assaf Model** | Col. | 19 | **0.683** | **1.035** | **0.966** | **1.120** |
| **Sharawy Model** | Col. | 22 | **0.762** | **1.100** | **0.909** | ----- |
| **Ahrar Model** | Col+Core | 31 | **0.985** | **0.574** | **1.742** | ----- |
| **Jazaer** | Col+Core | 35.9 | **1.100** | **0.470** | **2.128** | **2.220** |
| **Ganna Model** | Col+Core | 37 | **1.125** | **0.640** | **1.563** | **1.830** |

As can be seen from the results, all the investigated case studies showed discrepancies between the values calculated by code equation and between the two methods used in this research (i.e. ambient vibrations and analytical method).

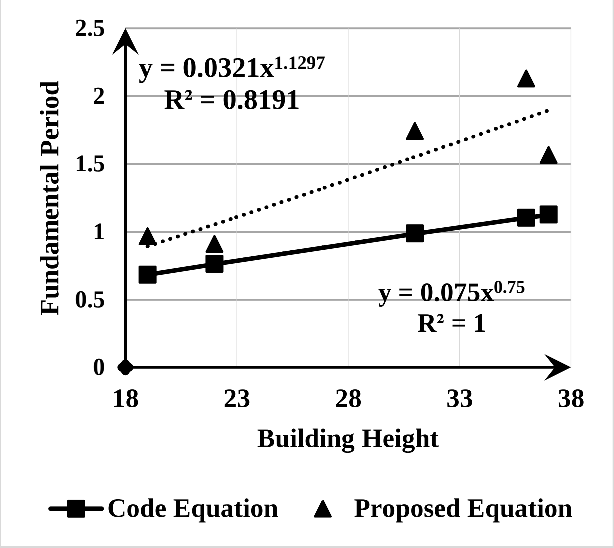

**Figure 24: Regression analysis chart for proposed equation for estimating fundamental period.**

The New Proposed Equation, **Figure 24**:

$$T = 0.0321\, H^{1.13} \qquad \textit{Eq.4}$$

### 6.2 Applications of New Proposed Equation on Tested Case Studies

After applying the regression analysis on the results obtained through in-situ study. The equation gave a confidence of 82% which is represented in the value of $R^2$ (coefficient of determination). The low confidence value is expected as the number of the case study is a small number. Similar studies should be performed to inspect more case studies including a variation in structural system, breadth and height as well. The next step is to test the equation and compare it to the proposed code equation and show the difference in pursuit of shedding some light on the problem, table 8.

As clearly seen from the results, applying the new proposed equation significantly decreases the difference between analytical and ambient vibrations results. The maximum difference between the new proposed equation and analytical method (FEM) was 33%. That means the error was decreased up to 150 %.

**Table 8. Comparison between results obtained during In-situ measurements after applying new equation.**

| No. of Floors | Structural System | Height | Code Eq. | Proposed Eq. |
|---|---|---|---|---|
| | | | $T = C_t H^{0.75}$ | $T = 0.0321\, H^{1.13}$ |
| | | meter | $C_t = 0.075$ | |
| **Assaf Model** | Col. | 19 | **0.683** | **0.894** |
| **Sharawy Model** | Col. | 22 | **0.762** | **1.050** |
| **Ahrar Model** | Col+Core | 31 | **0.985** | **1.555** |
| **Jazaer** | Col+Core | 35.9 | **1.100** | **1.836** |
| **Ganna Model** | Col+Core | 37 | **1.125** | **1.841** |

## 7 CONCLUDED REMARKS

This study demonstrates the significance potential of integrating ambient vibrations into extracting modal parameters. The experimental results showed a huge discrepancy between fundamental periods extracted using ambient vibrations and code equation. Moreover, the results showed that the code equation always gives shorter period which implicates that the buildings are stiffer than reality. This assumption can misrepresent the real behavior of the building during earthquake resulting in an unsafe design. However, in slender structures such as mosques minaret (Maazana) that might not be the case. In other words, the code equation would rather give a longer period which can lead to catastrophic results if this issue is overlooked. The implications of this study are far reaching, particularly in damage detection techniques where performance of the building is critical. However, similar studies should be performed to inspect more case studies including a variation in structural system, breadth and height as well.

### 7.1 In-Field Study

Based on the earlier discussion of the use of in-situ study the following conclusions can be drawn:

- The effect of soil parameters, type of foundation, and infill walls was obvious. Neglecting or considering their effect will produce a difference during modeling process. The maximum difference was ranged between (15-70.26) % for all study cases.

- The difference between the extracted frequencies from (FEM) and in-situ measurements using ambient vibrations ranged between (1-8.88) %
- The difference between using the code equation (ECP-201, 2012) and FEM was ranged from (64 – 200) %, while applying the new proposed equation was ranged between (30-33) %.
- A more elaborate testing for existing structures should be performed as it would allow for the derivation of a more reliable equation based on several parameters, for instance, structural breadth same as it was in the (ECP-93).
- During in-situ measurements, it is rather better to choose buildings with no surroundings to avoid having additional noises in fundamental frequencies. These noises can be attributed to torsional modes that cannot be detected while in-situ.
- Large structures gave a huge difference between modelling and code prescribed equation for estimating the fundamental period. That can be attributed to neglecting the structural breadth.

### 7.2 Proposed Equation

Based on the earlier discussion of new proposed equation results the following conclusions can be drawn:

- The maximum difference between the Egyptian code prescribed equation and analytical method (FEM) was up to 200 % as can be seen in case study 2 (Jazaer tower).
- Using ambient vibrations technique, the maximum difference was up to 192 %
- Both techniques showed huge discrepancy in single case study, this was due the slenderness of the tested building, which raise the question for using the height only as a parameter without considering other parameters of RC buildings.

### 7.3 Future Work

Finally, Future research should focus on developing more effective equation that includes the effect of building dimension. Moreover, further studies and in situ or laboratory tests are needed to be performed in several regions across the nation especially for building constructed on raft foundation. The future studies will allow us to come up with a procedure which would have the reliability to evaluate the fundamental period of a building, particularly to better understand the large differences between numerical and experimental values.

### Authorship Contribution Statement

**Moataz Elrayes**: Writing - original draft, Formal analysis, Software, Investigation, Visualization.

**Ezzaat Sallam**: Conceptualization(supporting), resources, Writing - original draft (supporting), Writing - review and editing, Supervision.

**Emad Abdel Galil:** Conceptualization, Supervision, writing -review and editing.

### Declaration of Competing Interest

There have been no involvements that might raise the question of bias in the work reported or in the conclusions, implications, or opinion stated.

## REFERENCES

[1] H. Gavin, S. Yuan, J. Grossman, E. Pekelis, and K. Jacob, “Low-Level Dynamic Characteristics of Four Tall Flat-Plate Buildings in New York City by,” 1992.

[2] *ECP 201. Egyptian Code of Practice No-201 for Design Loads for Construction Works, Research Center for housing and Construction, Ministry of Housing, Cairo, Egypt, 2012*.

[3] C. S. Oliveira and M. Navarro, “Fundamental periods of vibration of RC buildings in Portugal from in-situ experimental and numerical techniques,” *Bulletin of Earthquake Engineering*, vol. 8, no. 3, pp. 609–642, Jun. 2010, doi: 10.1007/S10518-009-9162-1/METRICS.

[4] R. K. Goel and A. K. Chopra, “Period Formulas for Concrete Shear Wall Buildings,” *Journal of Structural Engineering*, vol. 124, no. 4, pp. 426–433, Apr. 1998, doi: 10.1061/(ASCE)0733-9445(1998)124:4(426).

[5] H. Crowley and R. Pinho, “Period-height relationship for existing European reinforced concrete buildings,” *Journal of Earthquake Engineering*, vol. 8, no. May 2014, pp. 93–119, 2004, doi: 10.1080/13632460409350522.

[6] W. A. E.-W. Mohamed, “Parametric Study on the Effect of Masonry Infill Walls on the Seismic Resistance of Rc Buildings,” *JES. Journal of Engineering Sciences*, vol. 40, no. 3, pp. 701–721, 2012, doi: 10.21608/jesaun.2012.114405.

[7] F. Chalah, L. Chalah-Rezgui, K. Falek, S. E. Djellab, and A. Bali, “Fundamental Vibration Period of SW Buildings,” *APCBEE Procedia*, vol. 9, pp. 354–359, 2014, doi: 10.1016/j.apcbee.2014.01.062.

[8] Tom irvine, “https://endaq.com/pages/vibration-shock-analysis-software-vibrationdata-toolbox?utm_source=youtube&utm_medium=video&utm_campaign=download-software&utm_content=how-to-calculate-velocity-from-acceleration-data-to-vibrationdata-toolbox.”

[9] M. El-Rayes, E. Ahmed Sallam, E. Yehia Abdel-Galil, and by Author, “Numerical Assessment of

Building Vibration Techniques Using Laboratory Models," *Port-Said Engineering Research Journal*, vol. 26, no. 1, pp. 57–67, Mar. 2022, doi: 10.21608/PSERJ.2021.67135.1099.

[10] SAP2000.V15, "https://wiki.csiamerica.com/display/sap2000."

[11] ETABS.V17, "https://www.csiamerica.com/products/etabs.".

[12] R. Brincker and C. E. Ventura, *Introduction to Operational Modal Analysis*. 2015. doi: 10.1002/9781118535141.

[13] Windy.APP, "https://windy.app/forecast2/spot/2654117/Port+Said+-+Port+Fouad+Ferry."