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Proposing the monitoring system of Milad Telecommunication Tower during construction and serviceability stages

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ABSTRACT: Lots of high rise buildings are constructed in the world and determining their structural behavior is one of the most important problems that could lead to the development of the current guidelines. One of the most economical ways for determining the above mentioned is to investigate the structural behavior of the existing tall buildings. This could be performed by monitoring of the structural response due to ambient vibration. There are lots of problems that occur within the monitoring of structural behavior and hence one of the most important problems in structural data acquisition and its analyzing is to ensue about the structural monitoring condition.

Milad tower is the forth high rise telecommunication tower in the world located in Tehran, Iran. The height of this tower is 435 meters. The head structure of this tower has 12 floors and is the largest head structure among the existing telecommunication towers. Considering these facts, the structural behavior and dynamic characteristics of this tower could be caused some improvements in estimating the structural response of such towers and could be used for improvement of the related design guidelines.

Designing a definitive monitoring system, instrument selection, installation procedure according to the finalized design FE model of Milad tower is the aim of this paper. Also, redesigning of the system based on restrictions that occurred during the installation of instruments will be clarified in this paper. The above system will be proposed in two stages: first system will be proposed for the construction stage and the second is for after construction and during serviceability of the tower. The conclusions of this paper will be compared with other monitoring systems that were performed on some of the largest tall buildings in the world and the advantages and disadvantages of each monitoring system will be discussed

1 INTRODUCTION

Lack of sufficient information during designing structures (i.e. concrete exact compression stress, steel exact yield stress, structural response during ambient vibration, earthquake exact loading characteristics and etc.) necessitate consideration of some hypothesis in the design of structures according to common practices. In this way, some safety factors are taken into account during design of the structures to reduce the unreal effects of such hypothesis.

Also, some simplified hypothesis in modeling is considered during design of structures and all of the details of the structure are not considered in the FE modeling as per structural guidelines.

Considering the above, one could conclude that the behavior of the constructed structure has some differences from design modeling based on the accuracy of the hypothesis.

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About the typical building, since these differences are minor and do not have major effect on structural response, normally, determining the exact structural behavior is not considered after construction of the building. But about special structures (i.e. tall buildings and bridges) determining the structural behavior is more important. Random loading (traffic, ambient vibration and earthquake) has more effects on structural behavior. Although, these loading were considered during design stage, but such special structures may have different responses against random loads and we may not be able to forecast the structural response during design stage with consideration due to Lack of sufficient information about the structural characteristics.

Monitoring of the structural response is one of the most common practices in the recent years. In this advanced method, one could obtain the structural static/dynamic characteristics considering the interaction between all important parameters. The unknown hypothesis during Design stage could be determined and improved by designing a monitoring system on the constructed building. The results could help the owners to strengthen the structure against random loading (i.e. design earthquake, design wind storm and etc.). Also, the results of monitoring of special buildings (i.e. super tall buildings) could be used for updating the related guidelines.

In this paper, the authors have described designing of the monitoring system, instrument selection, installation procedure according to the finalized design FE model of Milad tower. Redesigning of the system will be discussed and the proposed monitoring system during construction and serviceability will be presented.

2 MILAD TOWER GENERAL SPECIFICATIONS

Milad tower, as the case study of this paper, is the forth high rise telecommunication tower in the world located in Tehran, Iran. The height of this tower considering its antenna mast is 435 meters. The concrete shaft of this tower has 315 meter height and the antenna mast has 120 m height.The 12 floors head structure of this tower is the largest head structure among all of the existing telecommunication towers. Fig. 1 shows the isometric view of this tower. This tower has been designed at 1995 and its construction is finalized during 2008.

Figure 1. Isometric View of Milad tower

3 DESIGN OF MONITORING SYSYEM

3.1 Design procedure

The aim of structural monitoring of high rise buildings is to determine their actual static/dynamic characteristics and for health monitoring of the structure subjected to critical ambient vibrations (i.e. wind storms and earthquake). Some items proposed in the design of Milad tower's structural monitoring system are presented as the following:

- Calculating the dynamic characteristics of the tower (i.e. natural frequency, mode shapes and damping ratio) according to designed FE model.
- Selection of required instruments/sensors based on the above dynamic characteristics.
- Designing the monitoring systems (i.e. sensor locations and layouts, data transferring systems, data analyzing systems and etc.)
- Performing some ambient vibration recordings from the tower for assessing the actual behavior of the structure.
- Redesigning the monitoring systems based on the actual results obtained and restrictions occurred in the previous stage.
- Installation of the continual monitoring systems for health monitoring of the tower.

One of the advantages of the proposed methodology is performing ambient vibration tests during construction of the head structure and serviceability stage of the tower. The records in construction stage contain wind speed excitation equal to $25\,m/s$. The head structure additional mass affects on the structural response could be clearly determined from the results and these continual records could recommend some ideas about updating the FE model of the tower for health monitoring purposes.

3.2 Instrument selection and sensor arrangement

Accelerometers are the most common instruments used in tall building monitoring systems. Since the major dynamic characteristics of the tower (i.e. mode shape, natural frequency and damping) could be obtained using accelerometers, the ambient vibration recordings during construction were focused using these kinds of sensors. So, two servo accelerometers (Model ASQ-1CL made in Japan) were installed on elevations 302,280, 254, 228 and 60 meter to measure the acceleration responses of the tower.

The weight of the Milad tower is too much and there are no exciting systems for forced vibration application. Therefore, the ambient vibration method is used for structural monitoring of the tower. Fig 2 shows the arrangement of the accelerometers for installation during the construction stage. This arrangement is based on the results of dynamic analysis of the tower FE model (i.e. Mode shape) and the common practices performed on other tall buildings.

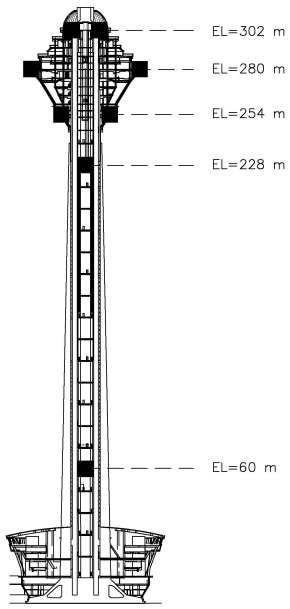

Figure 2. Proposed sensor arrangement on the Milad tower during construction

3.3 Redesigning of the monitoring system based of restrictions

The servo accelerometers transfer the recorded data via an analog system. This may cause two kinds of restrictions during the recordings. First, the analog systems are highly effected by electrical and high voltage cables and the received data in the central processing center may have two much noise. This condition is common in high rise buildings. Second, cables transferring the recorded data have some electrical resistance and since the excitation of the tower is in low frequency ranges there are some limitations in the cable length for appropriate data transferring. This problem occurred during structural response recording in two or more elevations at the same time.

By conversion of the data from analog to digital (A/D system), the above mentioned problem is eliminated in the monitoring during the construction stage. But, for better data transfer during the serviceability stage it is necessary to design a compatible network between the various sensors (i.e. accelerometer, inclinometers and anemometers) for data collection at the central processing center. One of the most advanced technologies used in this project is fiber optic cables. Therefore, the imposed noise may reduce and there is no cable length limitation for data transferin Milad monitoring system.

Continual serviceability of the tower, recognition of critical locations that may suffer from damages during incidents (i.e. concrete cone post tensioning at the Elevation 254 m, head structure and etc) and considering the results of the monitoring during construction stage leads to the installation of 10 biaxial accelerometers at elevations -9.30, 28, 96,180 and 240 m and 6 tri-axial accelerometers at elevations 280 , 302 and 435 m for health monitoring of Milad tower. It should be noted that one of the aims of using tri-axial accelerometer is to determine the effects of the rotary restaurant on the head structure vibration for more safety of the beneficiaries.

While a portable anemometer has been used in monitoring of structural response in the construction stage, it is proposed to use 3 anemometers at elevations 28,315 and 375 m. This

system helps to have a more accurate wind profile on tower area. Also, one could analyze the structural response and accelerometers excitation based on the available accurate wind profile.

Also, using two inclinometers are proposed for determining the structural inclination during ambient vibrations. Fig. 3 presents the proposed monitoring system for Milad Tower during serviceability stage.

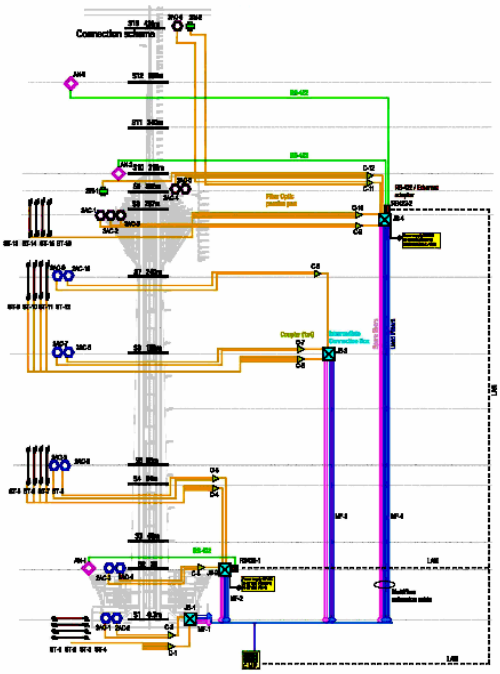

Figure 3. Proposed monitoring system for Milad Tower during serviceability stage

4 COMPARISION OF ANALYTICAL RESULTS WITH EXPERIMENTAL RECORDS

There is a good agreement between analytical results of the FE model and preliminary results (excluding damping ratio) of the records obtained at the end of tower construction. Fig. 4 shows the mode shape of the tower determined from the FE Model and experimental records.

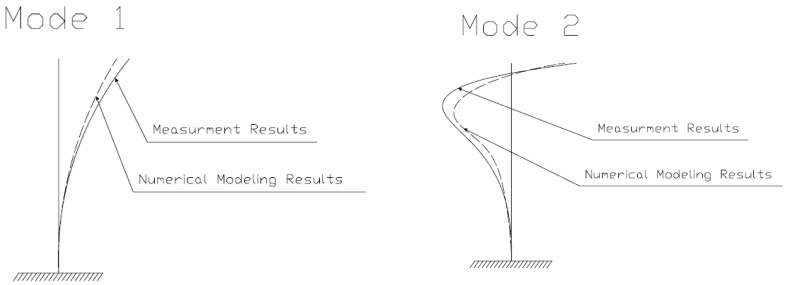

Figure 4. First two mode shape of the tower according to measurement and the FE model results

Table 1 presents the first three natural frequencies of the tower in different conditions:

Table 1. Comparison of experimental test results with analytical FE Model

Mode	Frequency (Hz)		Difference (%)
	Field Measurement	FE Model	
1	0.125	0.136	8
2	0.240	0.460	47
3	0.465	0.699	33

Because of some simplifications in the FE model and continuing construction operations, there are some differences in the results presented in the above table. Although the difference of results in the first mode of the structure is not substantial but there are some differences in the second and third mode. The location of the accelerometers and the recording frequency resolution has major effects on these differences. It should be noticed that some extra noises (i.e. working crane, elevators and etc) occur in the construction stage and the recording frequency resolution should not limited to Nyquist law. It is proposed to have 40 sample/second resolutions for the recording until one could truly filter the undesirable noise. This conclusion with other practices obtained in monitoring of structure during construction was included in designing of the continual monitoring system presented in Fig. 3.

5 COMPARISION OF PROPOSED MONITORING SYSTEM WITH THOSE PERFORMED ON OTHER HIGH RISE BUILDINGS

Some of the high rise buildings that were instrumented for determining their structural response are Di Wang tower with 384 m height, Jin Mao tower with 420.5 m height, John Hancock tower with 244 m height and Guangdong tower with 200 m height. In all of these cases some accelerometers on the top floors of the tower were installed for determining the structural response. Only for John Hancock tower the recordings were started from the construction stage. Table 2 presents a brief description of the monitoring systems installed on the above towers.

Table 2 Monitoring systems of some tall buildings

Tower Name	Height (m)	Sensor Type	Sensor Number	Sensors Installation elevation	Remark
Di Wang	384	Accelerometer	2	348.0 m	
		Anemometer	2	298.3 m	
		Displacement Transducer	2	298.3 m	
Jin Mao	420.5	Accelerometer	2	76th floor	The tower has 88 floors.
			2	69th floor	
John Hancock	244	Accelerometer	4	57th floor	Accelerometers are biaxial
			4	35th floor	
Guangdong	200	Accelerometer	2	62nd floor	Accelerometers are biaxial

As could be seen in the above table, the performed monitoring systems are for obtaining the structural characteristics like those performed during construction of Milad tower. In this case, the number of monitored locations on Milad tower is more than other tall buildings. This help to have accurate evaluations for mode shapes and damping ratio of the structure. None of the above buildings have continual monitoring systems for determining the health of the tower during serviceability and updating the model for determination of further damages.

6 CONCLUSION

In this paper the continual monitoring system design is proposed for Milad tower and the major conclusions are as the following:

- Proposing the design procedure for design of the continual monitoring system.
- Proposing two monitoring systems during construction and tower serviceability.
- Redesigning and upgrading the system based on FE model and ambient vibration recordings during the construction stage.
- Comparing the proposed monitoring system with those performed on other high rise buildings and assessing the advantages of the proposed system.

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