MOVING TOWARD THE MULTIFUNCTIONAL BUILDING SUGGESTED BY PROFESSOR KOBORI

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ABSTRACT :

Far for pretending it could become a common practice in the near future, this paper illustrates some solutions where a sort of power harvesting from the structural response vibration could start an economic loop which would make the structural control expenses sustainable. Suspension bridges and GPS monitoring are coupled in a first screening toward the implementation of structural monitoring. Then, attention is then focused on a very special class of buildings. .

KEYWORDS: Structural control, Multifunctional buildings, Power harvesting, Tall buildings

1. INTRODUCTION

One of the last key-note lectures by Professor Kobori, perhaps the last in Europe, was held in Como, Italy, in the occasion of the Third World Conference on Structural Control, in April 2002 (Kobori, 2003).
He did testify his awareness that the main limitation to structural control comes from the maintenance (and replacement) policy required by the implementing devices. Professor Kobori wrote about his experience in managing such systems: “Our motivation for executing maintenance and replacement continuously depends on nothing but the research mind. It is difficult for the building’s owner to keep their motivation, because it is expensive …”. Professor Kobori did also mention a remark and a proposal: (i) extremely large earthquakes could “occur tomorrow, in 10 years or 100 years”, but the control system should be ready at the occurrence of the event and (ii) “the control should be used not only for unusual events, … but also for routine events that are needed for daily life”. In summary it is stated that the building itself has a maintenance schedule time scale which is inconsistent with the one of the control system: the latter is rather comparable with the maintenance time scale of the equipments.
Five years later, the author attention was attracted by the design of an architecture team which conceived, for some Middle East location a building made of superimposed rotating storeys. Each of them was mounting wind turbines, so that the produced energy was enough for the building needs and for vending outside 20% of it! In this conception, the building becomes a machine, with the machine maintenance time scale, fully consistent with that of any control system one want to install.
Far for pretending this could become a common practice in the near future, this paper illustrates some solutions where a sort of power harvesting from the structural response vibration could start an economic loop which would make the structural control expenses sustainable. Suspension bridges (Kashima and Kitagawa, 1997) and GPS monitoring are coupled in a first screening. Then, attention is focused on some classes of buildings (Pelli et al., 1997).

2. LONG SPAN BRIDGES

Long span bridges (Calzona, 2008; Gimsing, 1997) offer a fascinating history that today was translated in current practice for span between 1 and 2 km. Even the old bridges as the Golden Gate in San Francisco or the Istanbul twin bridges were recently equipped with a monitoring system. (Yanev, 2005). Sometimes they are equipped with semi-active devices to mitigate cable vibrations or to reduce the deck oscillation (Casciati et al., 2006). The need of power is satisfied by links to the regional power network and, for sake of redundancy, to local power generators which automatically start in case the regional network fails to bring power (Wong, 2003; Kitagawa, 2003).

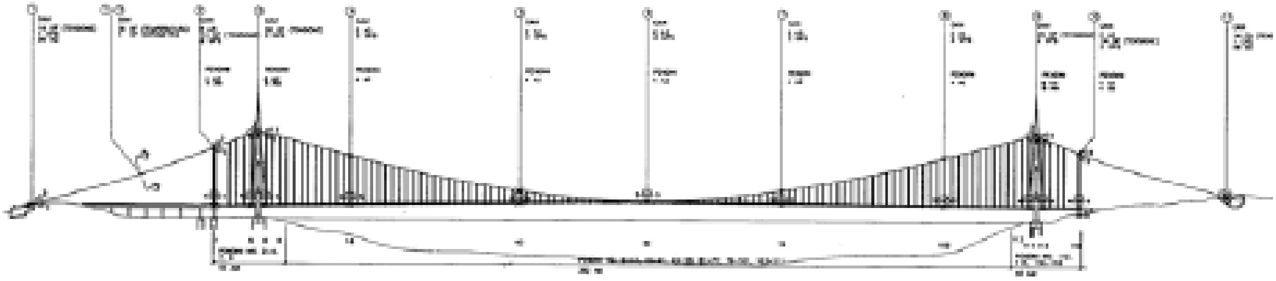

Figure 1 Monitoring device location along the cables of a suspension bridge.

Along and across the structure, however there is a secondary network (see Figure 1), some branches of which are of difficult access and likely to fail during the long lifetime expected for such bridges (from 100 to 200 years!). Therefore, a deep study of power harvesting is required in order to ensure remote sensor a longer life by recharging their re-chargeable batteries (Casciati et al., 2005; Casciati and Rossi, 2007).

In Figure 1, attention is focused along the cable geometrical development and along the height of each single tower. In particular the installation of GPS sensor units along the cables (Casciati and Fuggini, 2008) could find the power necessary for their mission from near-by solar panels and/or devices transforming in electrical power the mechanical one coming from the oscillations under environmental and man-made excitation. It is worth noticing here that the technology only allows to recharge items of limited power whose lifetime is presently not longer than five years.

3. SOME PERSPECTIVE IN ARCHITECTURE

Mainly the Asiatic countries started a sort of competition for real tall buildings (see Figure 2, where some recent constructions are compared with buildings designed and, in some cases, under construction). Within this competition, the Italian architect Fisher started the way, with the project in Figure 3a) to be realized in Dubai, of a new concept: the multifunctional structure..

It is made of superimposed rotating storeys. Each of them is mounting wind turbines, so that the produced energy is enough for the building needs and for vending outside 20% of it! In this conception, the building becomes a machine, with the machine maintenance time scale, fully consistent with that of any control system one could desire to install.

In a more recent proposal by the same architect the aesthetics of the building was ameliorated and the prospect in Figure 3d) was introduced.

ALREADY BUILT | **UNDER CONSTRUCTION**

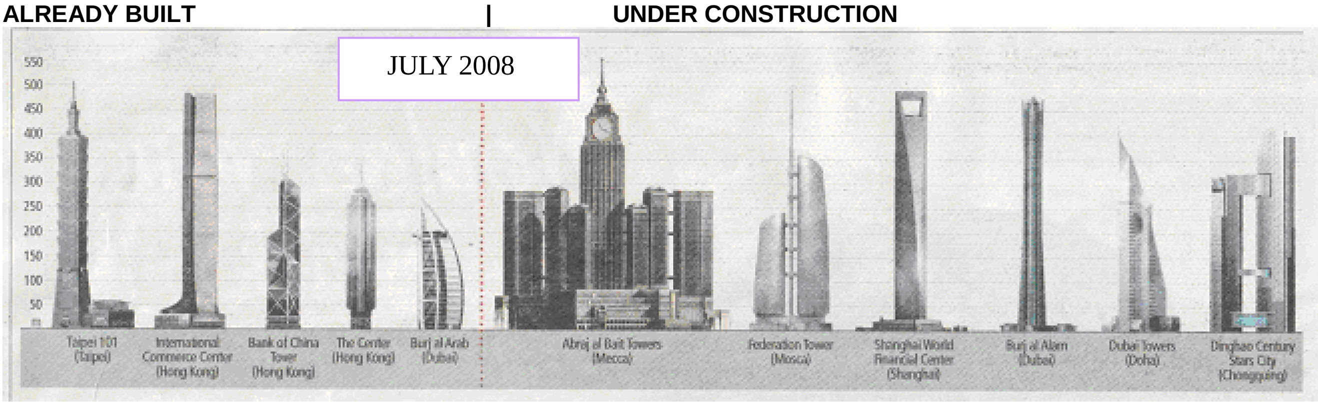

Figure 2 The ongoing tall building competition.

Figure 3 Project of multifunctional structure to be realized in Dubai (by Dr. Fisher): a) first proposal; b) ongoing design.

4. INVESTIGATING THE STRUCTURAL CONTROL POTENTIAL OF MULTIFUNCTIONAL BUILDINGS

In order to discuss the potential for structural control offered by such a multifunctional building, the numerical finite element model of Figure 4 was realized.

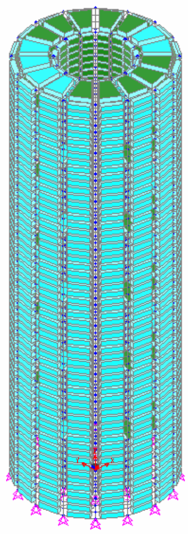

Figure 4 – Finite element model of the case study made of six superimposed blocks.

It is made of several -say six - superimposed blocks mounted along a central hollow pipe element of 10-meter

diameter surrounded by another 20-meter external pipe, the whole tower raised up to 60 meters high, divided into six equal stories (10 meters for each) by circular hollow slabs matching the dimensions of internal and external circular walls. Material used for constructing the model is assumed to be concrete for all parts of the model with weight over volume ratio equal to 24 kN/m^3.
Within this paper, they are not regarded as rotating (which is quite important in assessing the equivalent damping); a single block can only move up and down. The presence of either just one of them or two of them is studied. In particular, Figure 5 depicts three possible graded movements for two adjacent masses (floors) along the height of the tower, whereas Table I emphasizes how the frequencies of the system with these blocks changes according to the different positions of the blocks.

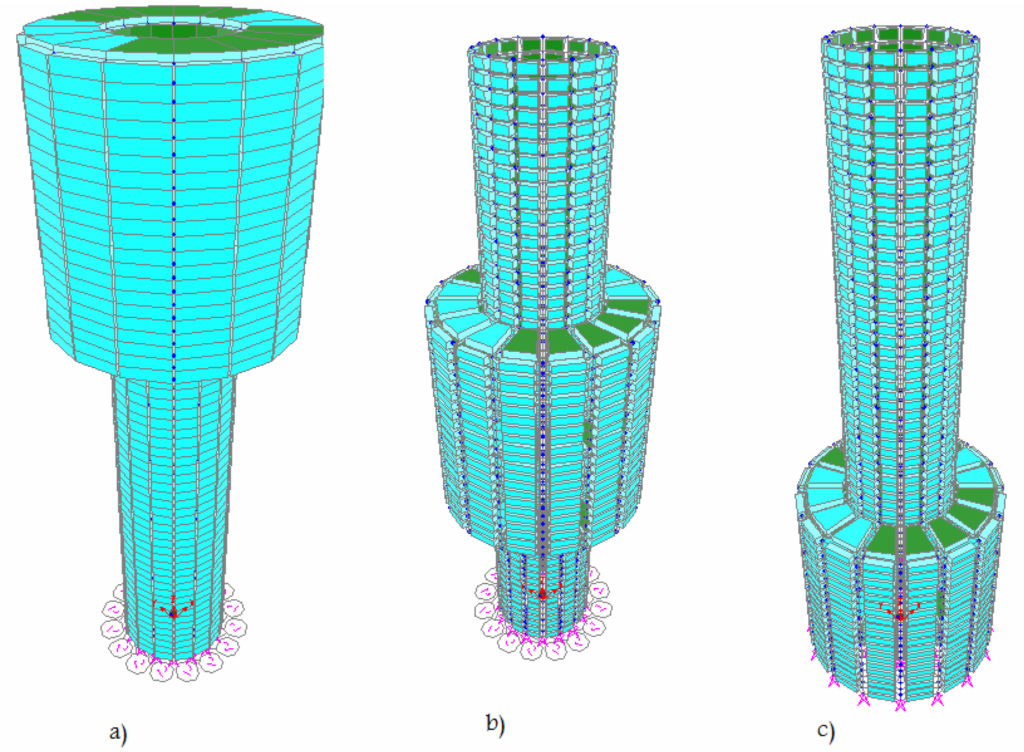

Figure 5 – Finite element model for three different locations of the block: a) upper; b) median; c) lower..

TABLE I: Modal Frequencies for cases shown in Figure 5.

	Figure 4	**Figure 5a**	**Figure 5b**	**Figure 5c**
Mode	**Frequency**	**Frequency**	**Frequency**	**Frequency**
	Cyc/sec	Cyc/sec	Cyc/sec	Cyc/sec
1	2.3154	0.87885	1.3103	2.4492
2	2.3154	0.87885	1.3103	2.4492
3	7.6252	3.1425	4.2303	9.9825
4	9.6187	5.5594	6.4699	9.9825
5	9.6187	5.5594	6.4699	11.639
6	11.833	6.4895	7.5004	13.789
7	19.411	15.122	12.984	16.683
8	20.18	15.122	12.984	16.683
9	20.18	17.373	16.463	17.58
10	22.848	18.118	17.377	17.58
11	23.019	18.118	17.377	18.747
12	23.019	23.112	23.447	18.747

In this paper; the model elements were built using a mesh of thin-shell elements to construct walls and slabs of the whole tower, also floors were assumed to be fixed for both rotating and elevating movements; in order to only measure the differences in frequency for the multi-positioning floor building.
Table 1 emphasizes how the scheme a) in Figure 5 is not adequate when the wind excitation is present, but offers its 3rd, 4th and 5th mode to an incoming seismic excitation. By contrast, scheme c) would put the system in safer conditions in the presence of strong wind, but should be avoided during a seismic motion. To confirm such a situation, one also studies the effect of larger number of masses –say four- located in different mutual positions along the total height of the tower. Three different cases are studied as depicted in Figure 6; systemically Table 2 signifies how the frequency is being changed upon the different positions of the masses. The frequencies in Table 2 show that despite the doubled masses, the range of frequencies is not altered so much.

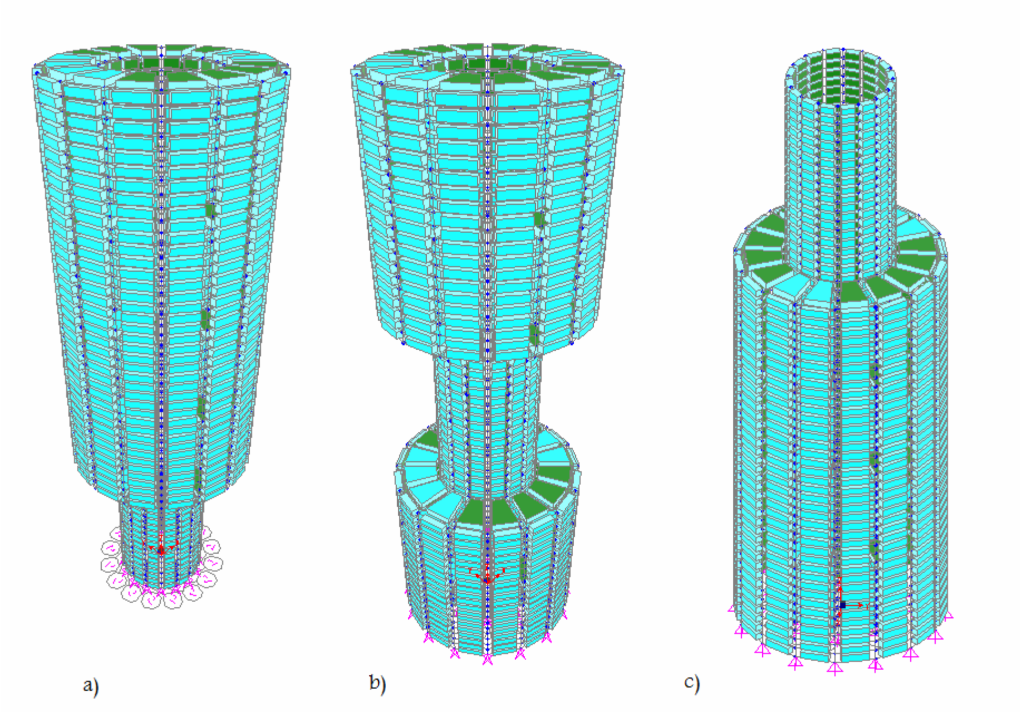

Figure 6 – FE model for three different locations of four out of six blocks.

TABLE 2: Modal Frequencies for cases shown in Figure 6

	Figure 6a	Figure 6b	Figure 6c
Mode	Frequency	Frequency	Frequency
	Cyc/sec	Cyc/sec	Cyc/sec
1	0.85759	1.2499	3.3735
2	0.85759	1.2499	3.3735
3	3.1938	4.1433	8.9252
4	5.8139	6.7141	8.9252
5	5.8139	6.763	10.768
6	6.1071	6.763	14.156
7	18.211	13.77	17.378
8	20.264	13.77	17.378
9	20.264	17.541	17.586
10	22.343	22.348	17.586
11	23.085	22.442	21.223
12	23.085	22.442	23.473

Further analysis study was carried out considering two separate non-adjacent masses, changing their locations along the six-floor tower from the third and sixth positions (Figure 7a) to the first and fourth positions (Figure 7b). The modal frequencies of the tower related to these changes are mentioned in Table 3.

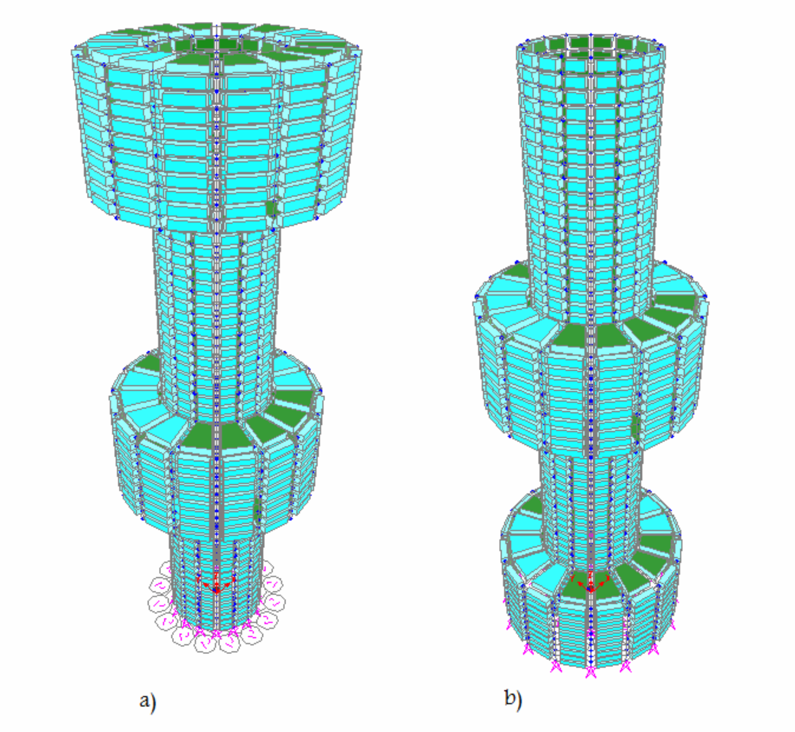

Figure 7 – FE model for two separate blocks in two different locations.

TABLE 3: Modal Periods And Frequencies

	Figure 7a	Figure 7b
Mode	**Frequency**	**Frequency**
	Cyc/sec	Cyc/sec
1	0.96893	1.5371
2	0.96893	1.5371
3	3.6389	5.3526
4	4.9772	7.4663
5	4.9772	7.4663
6	7.0807	8.401
7	9.5527	14.786
8	10.257	14.786
9	10.659	16.357
10	10.659	17.367
11	14.301	17.367
12	14.301	22.148

The values of Table 3 have to be compared with those in Table 1, and one immediately realize as this new possibility of relative motion between the architectural block give the structural designer the chance to dominate (control if this is automatically done in closed loop feedback) the higher bending modes of the structural systems.

CONCLUSIONS

As Professor Kobori stated in the conclusions of his lecture (Kobori, 2003): "To maintain control performance during the building life, periodic maintenance and replacement is required. … To better promote the worldwide application of seismic response control, … the seismic response control system should be a multi-functioned systems incorporating functions for daily life, security, information-technology systems and so on."
Fifteen years late, the proposal is still far from being implemented: current civil engineering structures mainly obey structural code (safety) recommendations and insurance duties, which do not leave room to such new concepts. Nevertheless, a sort of monumental architecture business is growing where economy is no longer the main issue, which is now to impress, to produce huge logos at no matter which the cost is. Within this special trend of modern architecture, the structural system as machine was independently achieved. Its parts are in relative motion and it is able to supply the necessary power by suitable wind-turbine. It is the foreseen multi-functional structure where the presence of moving architectural parts is the natural premise for any maintenance plan.
This contribution was just checking the feasibility of a control exploiting the vertical position of architectural block. The promising perspective comes exactly from the nature for which these blocks are conceived: they are supposed to rotate so that power is produced by suitable wind turbines. But this power production for the structure is just a form of energy dissipation, or, in a wide sense, of additional damping.

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