ACTIVE CONTROL FOR THE SERVICEABILITY OF CONTROL-TOWERS

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SUMMARY

Anxiety, fright, or even panic, can be induced in the operators of airport control towers by the oscillations caused by moderate earthquakes, with consequences on air traffic safety. The influence of an active control system, inserted at the top of the tower, in reducing movement and its effects is investigated. Results of numerical simulations carried out on a sample tower show that during moderate earthquakes, the response can be limited below the tolerability threshold. The system can also lower the troubling effects of wind induced motions below the satisfactory limit.

BUILDING SERVICEABILITY UNDER SEISMIC ACTION

The serviceability of buildings under seismic actions involves two aspects which can be defined "hardware serviceability" and "software serviceability". The former involves maintaining the function of structural and non-structural elements and of plants to ensure the full development of operations in buildings. The latter regards the occupants and the maintenance of comfort conditions which, although not optimum, are sufficient to assure the correct execution of their tasks.

When speaking about serviceability in seismic engineering, the first of the two aspects is usually and implicitly referred to and in fact, it deals directly with the seismic design of engineered components of buildings. Moreover, the second aspect does not regard all the buildings for which function must be maintained, but only certain special strategic buildings where operations requiring attention and concentration are carried out and no interruption can be tolerated. On the other hand, limitations deriving by the so defined "software serviceability" can be more restrictive, because the building movement compromising comfort can be very moderate due to the emotional response of human occupants.

Taking into account sensitive buildings such as airport control towers, short motions, like earthquakes of moderate intensity that do not damage structures nor endanger human life, can induce lateral oscillations which trouble the operators and jeopardise the appropriate execution of operations with risk for air traffic safety. Anxiety, fright, and even panic conditions occurred during the 1997-98 earthquakes in central Italy, even in airports far from the epicentre area. ENAV (Ente Nazionale Assistenza al Volo), the Italian authority supervising air traffic, pointed out the problem and asked for studies to be done on the means for providing proper safety conditions to tower operators when lateral oscillations occur.

In general, human perception of motion depends on several dynamic characteristics like frequency content, maximum acceleration and acceleration variation, and on other side factors directly influencing the emotional perception (noise, previous experience, etc.) that cannot be evaluated physically. In the event of short violent motions, according to the results of the experimental studies carried out on the subject, maximum acceleration seems to be the main physical parameter provoking discomfort and intolerability.

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The following correspondence between discomfort level and the values of the maximum acceleration, a_{max}, of the motion has been proposed [Chang, 1973]: the trouble is imperceptible for a_{max} less then 0.05 m/s^2 and is intolerable for a_{max} greater than 0.5 m/s^2; moreover trouble is "perceptible" in the range 0.05-0.15 m/s^2, "annoying" between 0.15 and 0.50 m/s^2 and "very annoying" in the range 0.5-1.5 m/s^2. Some tests [Yamada and Goto, 1975] confirm that people strongly perceive motions with acceleration over 0.4 m/s^2 and that perception is very annoying or intolerable for values greater than 0.5-0.6 m/s^2.

On this subject, studies [Irwin, 1975; Irwin, 1981] and specific guidelines [British Standard, 1984; DIN, 1975; ISO, 1984; ISO, 1995] regarding civil structures undergoing lateral oscillations under extended action can likewise be taken as a reference. This kind of action, like winds or works at construction sites, usually provokes loss of attention and discomfort: the vibration limits are expressed in terms of the maximum velocity or the r.m.s. of the acceleration as function of the motion frequency. In case of winds, thresholds are defined probabilistically and correspond to an oscillation intensity, caused by the worst ten minutes (peak) of a wind storm having a return period of five years, adversely commented by no more than 2% of the occupants.

ISO guidelines provide graphs in which the satisfactory limit for the acceleration r.m.s. varies from 0.035 to 0.025 m/s^2 for frequencies ranging from 0.5 to 1.0 Hz. The limit values of acceleration r.m.s. suggested by British Standard for vibrations with a short duration originated by works range from 0.080-0.160 m/s^2, while a tolerable maximum velocity of 48 mm/s can be assumed, evaluating it as the product of the basic reference value of 0.8 mm/s for a multiplying factor of 60, valid for residential buildings during the daytime.

Such limitations are very restrictive and could be incompatible with the response to a seismic input, even if moderate. But the causes of discomfort are very different in the two cases: extended actions provoke loss of attention, uneasiness, sickness, and continuous movement perception has to be limited; on the contrary, stronger short motions provoke excitability, fright and panic, and the perception of the motion peaks has to be reduced. In the following evaluations the maximum absolute acceleration value is assumed to be the parameter which controls the human response to short and violent motions, like earthquakes, and a value of 0.5 m/s^2 is referred to as satisfactory limit to avoid panic.

ACTIVE CONTROL SYSTEM

The typical structural scheme of control towers (inverse pendulum) make them very sensitive to lateral dynamic actions inducing vibrations, especially in their first mode of oscillation. The application of a hybrid control systems is hypothesised just for its high efficiency in reducing the response of systems characterised by a dominant frequency. Devices of this type have been already tested [Ankireddi and Yang, 1996] and sometimes installed on tall buildings [Fujita, 1993; 11WCEE, 1996].

Hybrid systems are characterised by high efficiency of the control, low sensitivity to the site conditions, efficiency against different dynamic actions, and selectivity of the control target. They represent a middle path between active and passive systems, in an attempt to optimise advantages and disadvantages: like passive systems, they modify one or more of the structure parameters (mass, stiffness, damping) while, like active systems, they supply energy to the structure but require the availability of lower power.

Algorithms of control are well established in the literature [Soong, 1990]. Using **M**, **C** e **K** to refer to the mass, damping and stiffness matrixes; $\mathbf{x}(t)$ to the vector of displacements; $\mathbf{f}(t)$ and $\mathbf{L_E}$ to the load vector and the location matrix; $\mathbf{u}(t)$ and $\mathbf{L_C}$ to the control action vector and the location matrix, the general matrix equation of a controlled system is

$$\mathbf{M}\cdot\ddot{\mathbf{x}}(t)+\mathbf{C}\cdot\dot{\mathbf{x}}(t)+\mathbf{K}\cdot\mathbf{x}(t)=\mathbf{L}_C\cdot\mathbf{u}(t)+\mathbf{L}_\mathrm{E}\cdot\mathbf{f}(t) \tag{1}$$

which can be written in the state space as

$$\dot{\mathbf{z}}(t)=\mathbf{F}\cdot\mathbf{z}(t)+\mathbf{G}_C\cdot\mathbf{u}(t)+\mathbf{G}_E\cdot\mathbf{f}(t) \tag{2}$$

under the positions

$$\mathbf{z}(t)=\begin{Bmatrix}\mathbf{x}(t)\\ \dot{\mathbf{x}}(t)\end{Bmatrix} \qquad \mathbf{F}=\begin{bmatrix}\mathbf{0} & \mathbf{I}\\ -\mathbf{M}^{-1}\cdot\mathbf{K} & -\mathbf{M}^{-1}\cdot\mathbf{C}\end{bmatrix} \qquad \mathbf{G}_C=\begin{bmatrix}\mathbf{0}\\ \mathbf{M}^{-1}\cdot\mathbf{L}_C\end{bmatrix} \qquad \mathbf{G}_E=\begin{bmatrix}\mathbf{0}\\ \mathbf{M}^{-1}\cdot\mathbf{L}_E\end{bmatrix} \tag{3}$$

Assuming a finite time interval τ, equation (2) can be solved and the state variable **z** can be computed step by step as

$$\mathbf{z}(n\tau+\tau)=\mathbf{A}\cdot\mathbf{z}(n\tau)+\mathbf{B}\cdot\mathbf{u}(n\tau)+\mathbf{P}\cdot\mathbf{f}(n\tau) \tag{4}$$

where

$$\mathbf{A}=\exp\{\tau\cdot\mathbf{F}\} \qquad \mathbf{B}=\mathbf{F}^{-1}\cdot(\mathbf{A}-\mathbf{I})\cdot\mathbf{G}_C \qquad \mathbf{P}=\mathbf{F}^{-1}\cdot(\mathbf{A}-\mathbf{I})\cdot\mathbf{G}_E \tag{5}$$

The system hypothesised in the current application is designed to function according to the linear quadratic optimum control algorithm [Soong, 1990] and that is, to provide for minimising the quadratic scalar index

$$J=\frac{1}{2}\cdot\mathbf{z}(t_f)^T\cdot\mathbf{S}\cdot\mathbf{z}(t_f)+\frac{1}{2}\cdot\int_{t_0}^{t_f}\left\{\mathbf{z}(t)^T\cdot\mathbf{Q}(t)\cdot\mathbf{z}(t)+\mathbf{u}(t)^T\cdot\mathbf{R}(t)\cdot\mathbf{u}(t)\right\}dt \tag{6}$$

Matrixes **S**, **Q**, **R**, control the final state, $\mathbf{z}(t_f)$, the current state, $\mathbf{z}(t)$, and the control force, $\mathbf{u}(t)$, respectively.

The control force can be determined at each step with the expression

$$\mathbf{u}(t)=-\mathbf{D}(t)\cdot\mathbf{z}(t) \tag{7}$$

in which **D** is the "gain" matrix

$$\mathbf{D}(t)=\mathbf{R}(t)^{-1}\cdot\mathbf{G}_C{}^T\cdot\mathbf{P}(t) \tag{8}$$

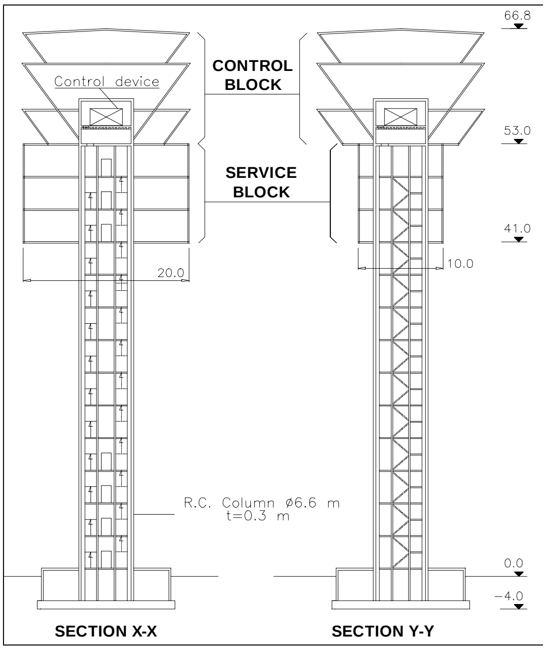
If **Q** and **R** are constant, and making other simplifying hypotheses, **D** results in a constant matrix and can be computed in advance, and the “cost function” index (6) becomes

$$J=\frac{1}{2}\int_0^{t_f}\left\{\mathbf{z}(t)^T\cdot\mathbf{Q}\cdot\mathbf{z}(t)+u^2\cdot R\right\}dt \tag{9}$$

THE CASE STUDY

A typical configuration, representative of the most recent towers, was suggested by ENAV to study the simulated behaviour when it is equipped with a hybrid control system. Figure 1 shows the scheme of the tower with a total height of 66.8 m. The main elevation structure is a r.c. column, 57.5 m high, having a circular hollow shape with an external diameter of 6.60 m and wall thickness of 0.30 m, which includes the elevator and the stairs. The column supports a three level control block shaped like superimposed inverse frustums of cone with a main diameter of 20 m. Located below it is a three-level service block having a sectioned circular plant, with overall dimensions of 20 x 10 m. Both blocks have a cantilevered steel structure. The tower is founded on a circular (diameter 16.50 m) r.c. plate stiffened by radial and perimeter walls. The mass values resulting from the load analysis are: 509 t for the service block, 350 t for the control block and 26 t/m for the column. The fundamental frequency of the tower is 0.606 Hz. The hybrid control system is located in a room at the top of the r.c. column, above the engine room of the elevator.

Figure 2 shows the plan, the vertical section, and the main mechanical parameters of the device. The control device consists of a lead mass sliding on a support platform which, in turn, slides on the fixed base along a



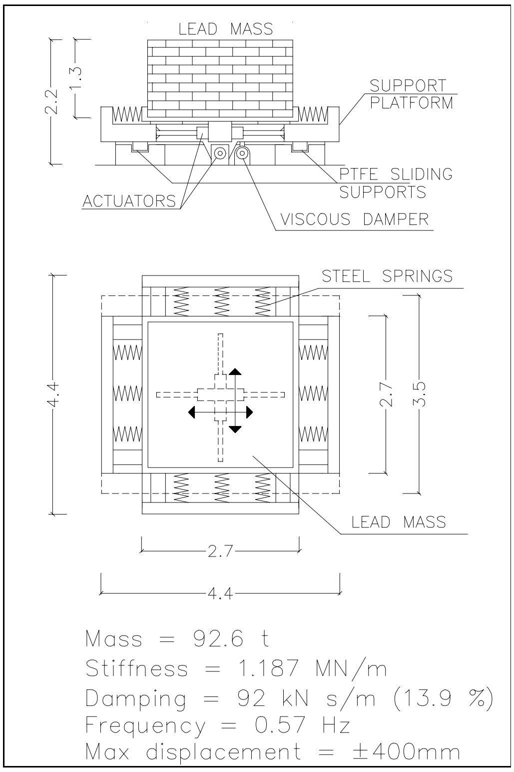


Figure 1: case study tower

Figure 2: device layout

normal direction. Steel-PTFE rails allow sliding with low friction. Steel springs, contrasting the mass displacement make it possible to set up the suitable values of system stiffness and frequency: for optimum behaviour, the frequency of the oscillating mass is tuned to the fundamental frequency of the structure. Viscous hydraulic dampers, also in parallel, give the required damping. Control forces are applied on each of the two directions through a pair of actuators ruled by a controller fixing the forces as a function of the input type and the structure response, in accordance with the provided control algorithm. The controller operates under different algorithms applying the most suitable "gain" value for different external actions.

SIMULATION ANALYSES

Numerical simulations of structure response under dynamic actions are carried out on a 2 DOF system reproducing the displacements of the tower, in its first mode, and the device. The model parameters are:

M_1 = 1157 t, K_1 = 16.776 MN/m , C_1 = 88 kNs/m (ξ = 0.01) for the main structure;

M_2 = 92.6 t (≈8% of M_1), K_2 = 1.187 MN/m, C_2 = 92 kN·s/m (ξ = 0.139) for the device.

Three models are considered - with active control (a), without control (n), with the device performing in a passive way (p) - to compare the performances of the different structural systems.

The moderate earthquake taken as reference input is a IV/V-degree earthquake on the Mercalli scale, meaning a motion conventionally defined as "strong" and "noticed by everyone, with fright". According to the Neumann correlation [Trifunac and Brady, 1975] a corresponding peak ground acceleration (PGA) of 0.05 g is assumed.

Tower response is computed considering both recorded and generated accelerograms. Four motions recorded during the last earthquakes in Umbria (September 1997 - April 1998) are considered as having a natural PGA of the same order as the reference value. The intensities of the two components are scaled to have a PGA of the resultant equal to 0.05 g. These actual accelerograms have a short intense phase, which is a typical characteristics of the earthquakes at the site, and have acceleration response spectra with high amplification values at low periods, that rapidly decrease in the range of higher periods. Table 1 reports some characteristics of the accelerograms used. For each component, both the recorded PGA (left value) and the scaled value (on the right) are reported. The analyses for the recorded accelerograms are carried out assuming for the parameters of equation (9) the values R=0.001 and $\mathbf{Q} = \mathbf{0}$ except the term $Q(3,3)=10\cdot10^6$. Based on several attempts, these values prove to be the most suitable in order to minimise both the response parameters and the control actions.

Table 1: Recorded accelerograms

Accelerogram	1186		1190		1191		1193	
Date	26sep97 00:33		26sep97 00:33		26sep97 00:33		27sep97 09:40	
Site	Matelica		Spoleto Monteluco		Forca Canapine		Gubbio	
Magnitudo ML	5.6		5.6		5.6		5.8	
Epicentral dist.	27 km		35 km		39 km		42 km	
PGA_{NS}	0.046	0.045	0.038	0.035	0.065	0.047	0.066	0.036
PGA_{WE}	0.049	0.048	0.050	0.046	0.066	0.047	0.087	0.048

Moreover, ten spectrum-fitted accelerograms are generated, with reference to the response spectrum B for medium soils of [Eurocode 8, 1994], with PGA equal to 0.25 g and a duration of 30 s. Five accelerograms are generated with an exponential envelope of the acceleration $a = 0.5 \times (e^{-0.09t} - e^{-0.4t})$ and the other five using a trapezoidal envelope with a constant threshold of 15 s and raising and decreasing branches of 5 and 10 s, respectively. When generated accelerograms are considered, control parameters R=0.01 and $Q(3,3)=5 \cdot 10^6$ are assumed because the previous values, adequate for short strong motions, would require performances that are not compatible with the hypothesised apparatus. In any case, the computation algorithm takes into account limitations of the applied force and of the available power consequent of the assumed sizing of the hydraulic circuit, which is illustrated further ahead.

Table 2 below summarises the main parameters of the response of controlled (a) and non controlled (n) models to real accelerograms: the maximum structure acceleration (A_s), velocity (V_s) and displacement (D_s); the r.m.s. of structure acceleration (R_s); the maximum device acceleration (A_d), velocity (V_d) and displacement (D_d); the maximum force (F_d); the maximum instant power (W); the maximum instant total power (W_t) considering the contemporary functioning in the two directions.

Table 2: Response to recorded accelerograms

Accelerogram			1186NS	1186WE	1190NS	1190WE	1191NS	1191WE	1193NS	1193WE	Average
A_s	(a)	m/s^2	0.259	0.225	0.271	0.376	0.220	0.237	0.170	0.237	0.249
	(n)	m/s^2	0.450	0.579	0.418	0.427	0.467	0.450	0.348	0.482	0.453
R_s	(a)	m/s^2	0.035	0.029	0.029	0.032	0.024	0.023	0.021	0.023	0.027
	(n)	m/s^2	0.091	0.079	0.067	0.073	0.053	0.059	0.110	0.096	0.079
V_s	(a)	mm/s	6.6	5.7	6.0	5.8	6.5	8.5	5.3	6.1	6.3
	(n)	mm/s	41.3	39.4	37.7	29.7	19.4	22.8	57.8	49.2	37.16
D_s	(a)	mm	1.7	1.6	2.4	1.9	1.9	1.5	1.7	1.3	1.8
	(n)	mm	10.8	8.7	8.5	7.3	5.9	5.2	15.6	12.0	9.3
D_d	(a)	mm	180.0	208.3	290.4	251.5	229.6	180.7	163.2	129.6	204.2
V_d	(a)	mm/s	196.3	234.5	308.4	275.9	192.9	245.5	273.1	215.6	242.8
A_d	(a)	m/s^2	4.465	5.007	3.343	4.701	4.650	4.401	3.548	4.998	4.389
F_d	(a)	KN	378.2	383.4	343.9	345.8	385.6	385.3	334.6	348.3	
W	(a)	kW	47.9	52.0	60.4	53.9	34.3	71.7	46.8	37.6	
Wt	(a)	kW	55.2		105.1		74.6		53.2		

As shown by the reported values, the assumed control system allows the reduction of the maximum value of the response acceleration from 0.45 m/s^2 to 0.25 m/s^2 in terms of average values on the eight accelerograms, that is from a high to a very low value in the "annoying" range. The r.m.s. of accelerations is reduced three times (from 79 to 27 mm/s^2) and the maximum velocity six times (from 37.1 to 6.3 mm/s). These values are even below the satisfactory limits [British Standard, 1984; ISO, 1984] suggested for actions with a long duration and therefore, the vibration can be considered fully acceptable without any loss of comfort. The maximum value of the required instant total power is 105 kW, taking into account the contemporary action of the two actuators along the two directions.

The results related to the generated accelerograms are reported in Table 3 with the usual notations of the considered parameters. In this case, the use of the control system reduces the maximum values of the response acceleration below the annoying limit of 0.5 m/s^2, from very annoying or intolerable values ranging from 0.76 m/s^2 to 1.19 m/s^2. The r.m.s. of accelerations is reduced from 0.29 to 0.11 m/s^2 and the maximum velocity from 177 to 36 mm/s, until it drops below the limit of 48 mm/s resulting [British Standard, 1984] for vibrations with an extended duration. The maximum required instant power results 157 kW, depending on the limitations imposed on the hydraulic circuit.

Table 3: Response to generated accelerograms

Accelerogram			01	02	03	04	05	06	07	08	09	10	Av.ge
A_s	(a)	m/s^2	0.436	0.452	0.439	0.403	0.387	0.439	0.461	0.473	0.434	0.477	0.440
	(n)	m/s^2	0.860	0.984	1.190	0.758	0.895	0.997	1.144	0.789	0.925	1.090	0.963
R_s	(a)	m/s^2	0.103	0.102	0.103	0.100	0.103	0.111	0.112	0.110	0.115	0.115	0.107
	(n)	m/s^2	0.239	0.284	0.336	0.241	0.253	0.356	0.340	0.278	0.231	0.329	0.289
V_s	(a)	mm/s	37.5	31.1	41.3	40.9	43.8	33.5	34.2	32.5	33.0	36.5	36.4
	(n)	mm/s	175.6	156.7	202.6	142.0	141.5	191.5	234.3	176.8	146.0	198.5	176.55
D_s	(a)	mm	9.9	8.8	12.7	11.2	8.9	8.1	7.1	9.1	11.4	9.5	9.7
	(n)	mm	44.2	43.9	54.0	37.4	41.1	52.5	57.4	44.0	32.9	55.4	46.3
D_d	(a)	mm	291.3	250.1	387.7	347.2	297.6	227.8	219.4	302.7	317.5	322.2	296.4
V_d	(a)	mm/s	717.3	711.2	804.2	872.7	931.4	790.9	703.8	677.4	777.7	594.4	758.1
A_d	(a)	m/s^2	3.693	3.845	3.550	3.677	4.610	3.381	3.862	3.265	3.967	3.636	3.749
F_d	(a)	KN	384.0	380.5	384.9	378.9	361.5	376.2	317.4	311.3	345.9	335.5	357.6
W	(a)	kW	130.3	153.1	157.4	153.5	133.5	140.0	128.6	137.1	157.4	153.0	144.4

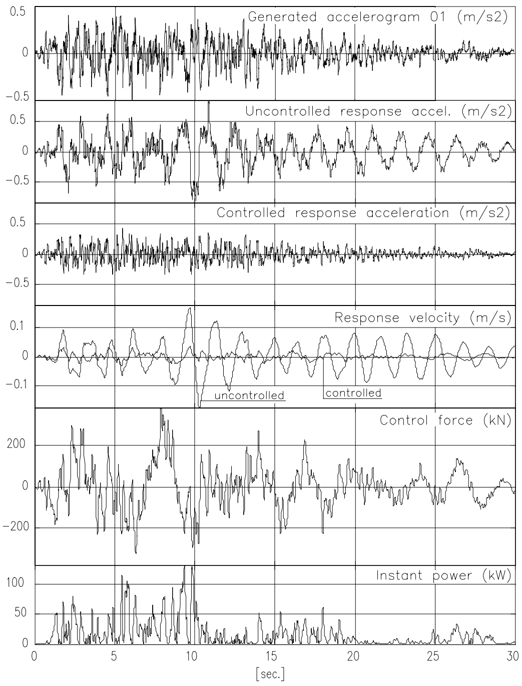
Lastly, Table 4 reports the usual response parameters for the case of the device performing in a passive way and that is, with the mass freely sliding on the supports without any force applied and without an energy supply. There are no advantages in the case of the recorded accelerograms and in fact, the maximum response acceleration remains practically unchanged. However, if generated accelerograms are considered, the reduction is still effective, i.e. around 25% in terms of maximum acceleration and velocity. These results indicate that a passive device cannot be adequate for the purpose of reducing system vibration to the suitable limit, but in the event of malfunction of the active system, a response improvement can nevertheless be obtained.

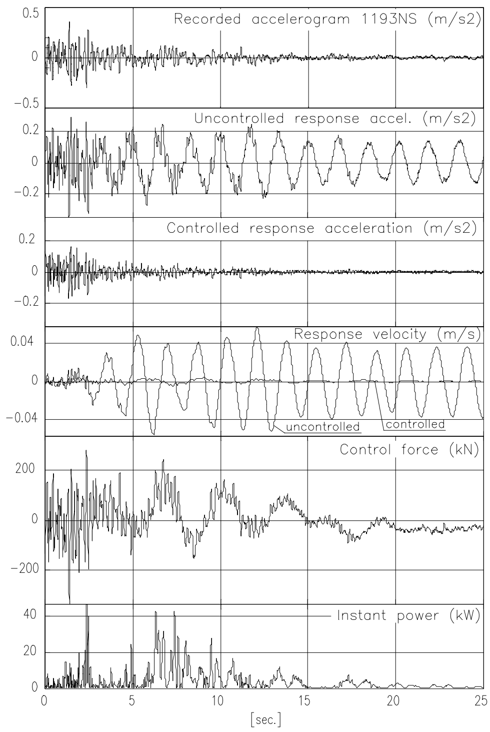
Table 4: Response of the passive performing system – Model (p)

Rec. accel.		1186NS	1186WE	1190NS	1190WE	1191NS	1191WE	1193NS	1193WE		
A_s	m/s^2	0.450	0.552	0.414	0.426	0.467	0.452	0.350	0.480		
R_s	m/s^2	0.078	0.029	0.057	0.069	0.052	0.055	0.057	0.058		
V_s	mm/s	24.3	25.8	32.4	27.7	14.8	20.0	32.0	25.2		
D_s	mm	5.5	6.8	6.9	4.8	4.4	4.1	9.9	6.3		
D_d	mm	17.6	13.8	14.1	13.5	11.8	10.7	30.8	20.6		
Gen. accel.		01	02	03	04	05	06	07	08	09	10
A_s	m/s^2	0.723	0.769	0.771	0.633	0.859	0.672	0.796	0.711	0.925	0.787
R_s	m/s^2	0.187	0.191	0.182	0.179	0.182	0.190	0.199	0.202	0.194	0.185
V_s	mm/s	132.6	129.9	99.5	127.4	125.4	111.4	119.0	115.0	134.1	116.4
D_s	mm	27.6	28.3	32.3	29.0	37.1	25.4	26.4	30.0	30.7	26.3
D_d	mm	81.4	89.8	87.5	84.2	84.7	81.3	80.0	90.2	79.2	84.4

As an example of the time evolution of the response, Figure 3 shows the time histories of some significant parameters for the generated accelerograms 01 and for the recorded accelerogram 1193NS. The ground accelerations, response accelerations and velocities both with active control and without control, the control force and the instant power are reported; the ordinate scales are different in order to make the results visible. The reduction of peak values when control is applied is evident, but the greater uniformity of the response and the consequent reduction of the r.m.s can also be appreciated. The response is no longer characterised by a dominant frequency, and the maximum values of power are required only for a limited time range (5-10 seconds). The control of the actual accelerogram response is more efficient because it requires less power with respect to what is available, which is dimensioned for the generated accelerograms.

The system has been also tested under simulated wind actions and it shows a high efficiency in also reducing the vibrations induced by extended excitation. Detailed results on the subject are reported in a separate paper [Mezzi et alt., 1999]. Winds with an average speed of 35 m/s and peak speed of 50 m/s have been considered. The r.m.s. of the response acceleration is reduced to 0.030 m/s^2, below the threshold satisfying the operators' comfort.



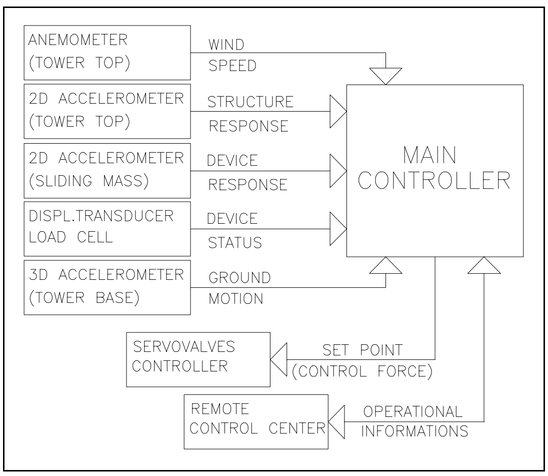


a) Generated accelerogram 01 **b) Recorded accelerogram 1193NS**

Figure 3: Input and response time histories.

CONTROL DEVICE APPARATUS

The instrumentation scheme and the data flow chart of the control system are reported in Figure 4. A 3D accelerometer station, located near the base of the tower, measures the ground motion accelerations. The acceleration response of both the tower and the device are read by other accelerometers and processed in terms of velocity and displacements. Load cells (LC) and displacement transducers (DT) read the actual values of the force applied by actuators and their displacements. The controller uses these input data to modify the response on the basis of the predefined set-point: using the suitable "gain" value, it computes the forces to be applied to the mass and applies them by sending a signal to the servovalves regulating the actuators. A remote control centre can be provided to which all the operational information can be sent and from which command action can be received. As the system is designed to control the wind response as well, an anemometer located at the top of the tower measures the wind speed representing the external action to be reported to the controller.



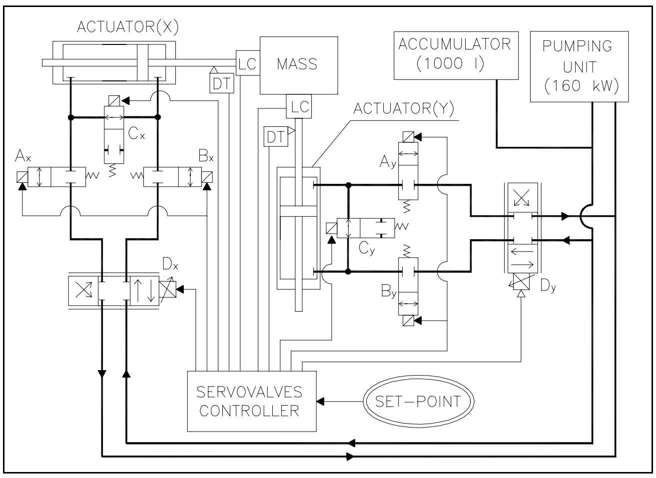


Figure 4: System data flow **Figure 5: Circuit layout**

The hydraulic circuit layout is reported in Figure 5. A pumping unit powered with a 160-kW engine supplies the circuit. Each circuit relative to the two actuators has a nominal delivery capacity of 360 l/min at a supply pressure of 315 bar and pressurised accumulators are provided, allowing supply for 30 s. The system characteristics enable the performances resulting from the numerical computations that have been carried out. Servovalves D_x and D_y control the movement of the actuator rams supplying the oil to one of the two chambers. If the actuator displacement is too large for the control system, valves A_x and B_x (and A_y and B_y) are closed while valves C_x and C_y are opened: thus the oil circulates between the actuator chambers and the device performs like a passive system. In an emergency situation or if the control proves to be inefficient, valves C_x and C_y are closed, blocking the motion of the device which becomes integral with the structure.

CONCLUSIONS

The results obtained analysing the numerical model of a sample control tower equipped with a hybrid control system and subjected to seismic input of moderate intensity show the efficiency of this control: lateral oscillations are contained below the tolerable limit for the human body, ensuring the operators' comfort and operational safety. Panic states can be avoided when moderate earthquakes occur, containing the maximum response acceleration below the annoyance threshold.

Performances are provided by a system characterised by actual values of mass, forces and power supplied by normal equipment. A suitable maintenance program of the system can be assured in a hi-tech setting such as the one found in a control tower.

The system performs effectively against different input actions, providing specific control algorithms automatically applied to different situation recognised by its surveying system.

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