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Traffic-Induced Vibrations on Structures

Vibrations causées par le trafic sur les constructions

Durch Verkehr verursachte Schwingungen an Bauten

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SUMMARY

The results of an experimental study carried out on several monuments in Rome are presented in this paper. The influence of the traffic-induced vibrations is investigated, especially with regard to the vibrations induced by the underground trains. An interesting solution used to preserve an ancient building in the centre of Rome is also discussed.

RÉSUMÉ

L'article présente les résultats d'une étude expérimentale sur différents monuments de Rome. L'effet des vibrations causées par le trafic a été analysé, spécialement celles provoquées par le métro. L'article présente aussi une méthode intéressante qui a été appliquée pour protéger un ancien bâtiment au centre de Rome.

ZUSAMMENFASSUNG

Der Bericht beschreibt die Ergebnisse von Untersuchungen einiger Denkmäler von Rom. Es wurden durch den Verkehr verursachte Schwingungen studiert, besonders die Schwingungen durch die Untergrundbahn. Der Artikel zeigt eine Lösung, die an einem alten Gebäude im Zentrum von Rom angewendet wurde.

1. INTRODUCTION

Traffic induced vibrations do not represent, in general, an immediate hazard to the structures but they can contribute, over the years, to their bad health status. This is certainly true for the constructions of the ancient cities, built when there was no traffic question. Examples of this kind are almost all the cities in Italy. Small streets, masonry buildings and often several monumental constructions, not preserved from the ambient around them, characterized them.

Traffic induced vibrations become very dangerous when acting on structures already damaged by earthquakes. Most of the architectural and monumental heritage in Italy live in this condition. In fact, it has suffered to various degrees during paste earthquakes, as described by historical documents [2, 3, 4]. On the other hand the strength of a structure under seismic actions can be deteriorated because of the continuous dynamic effects due to the traffic. Particularly dangerous are the vibrations due to the passing of the trains.

The first step in a preservation effort is the investigation of the health status of the structure. This can be performed by monitoring the construction in order to analyze their dynamic behaviour under both ambient and forced vibrations.

The results of an experimental study carried out on several monuments in Rome are shown in this paper. The research project was organized by the Italian Agency for New technologies, Energy and Environment (ENEA), in collaboration of the Archeological Commision of Rome. The measuraments were done by ISMES, on behalf of ENEA [7].

The effects of the traffic induced vibrations are investigated, especially with regards to the vibrations induced by the trains of the underground. The velocity amplitude and the structural resonances were pointed out. A comparison between the measured values and those suggested by the German Code was also done.

An interesting solution used to preserve a sixteen century building in Rome is also discussed.

2. EXPERIMENTAL INVESTIGATION AND DATA ANALYSIS

Seismometers and displacement trasducers were located in different time on each monument. The signals were recorded on magnetic tape by an analog recorder and then digitized with a high frequency sampling rate (0.005 sec). For each structure several registrations at different hours of the day and in different days were carried out.

Intervals of 30 minutes length of all the records were analyzed performing statistical and spectral analyses. The statistical analysis consisted in the calculation of the effective values and the peak values of the velocity over successive intervals lasting 1.28 seconds. The effective values were calculated using the formula

$$x_{ef} = \sqrt{\frac{\int_{t_1}^{t_n} x^2 dt}{t_n - t_1}}$$

where x is the recorded value and t_n-t_1 the time interval. In more detail, for each seismometer the positive, negative and absolute peak values were pointed out and the effective their maximum, minimum and average values with standard deviation were calculated.

In Tab. 1 are summarized the maximum values of the effective and peak values of the velocity on the basement and at the top of each monument.

For each monument the frequency domain analysis was carried out plotting the power spectral density for each record and the cross spectral density with the phase factor between a reference record and each of the other ones [3, 4, 5]. The coherence function was also calculated. Spectral analysis allowed to individualize the structural resonances and the first modal shapes on the basis of the spectral amplifications [1, 6].

3. TRAFFIC INDUCED VIBRATIONS EFFECTS

Almost all the velocity diagrams recorded at the basement of the monuments are characterized by a ground noise and intervals of higher vibrations. The ground noise is related to ambient vibrations and to the vehicular traffic. Vibrations of higher amplitude are due to the passing of the train. In fact, most of the considered monuments in Rome are near the underground. The amplitude of the vibrations during the passing of the train are four-five times higher than those relative only to the ground noise.

In Figs. 1 and 2 are plotted the records of the sensors located in the same horizontal direction, respectively on the basement and at the top of the Arco di Costantino. Figs. 3 and 4 show the diagrams of the effective velocities and Figs. 5 and 6 the diagrams of the peak values of the same records.

	Basement		Top	
Monument	Effective values	Peak values	Effective values	Peak values
Arco di Costantino	0.097	0.340	0.210	0.283
Tempio della Minerva Medica	0.115	0.379	0.711	2.210
Colonna Antonina	0.026	0.064	0.130	0.284
Colonna Traiana	0.033	0.094	0.340	0.478
Anfiteatro Flavio	0.122	0.155	0.121	0.325
Trofei di Mario	0.072	0.128	0.069	0.245
Terme di Caracalla	0.032	0.075	0.164	0.395

Tab. 1 Maximum effective and peak values of the velocity (mm/s)
on the basement and at the top of the monuments

The maximum values were compared with that suggested as the limit value of the velocity at the basement of historical constructions by German Code DIN 4150. This being equal to 2-3 mm/s, we can conlcude that the velocities of the traffic induced vibrations on the monuments in Rome are very low. Therefore they do not represent an immediate hazard to historical constructions.

In spite of that traffic induced vibrations may be very dangerous. It depends on the mechanical characteristics of the monument and on its structural state.

Monument	Effective values	Peak values
Arco di Costantino	2.16	0.93
Tempio della Minerva Medica	6.18	5.83
Colonna Antonina	5.00	4.44
Colonna Traiana	10.3	5.08
Anfiteatro Flavio	1.00	2.10
Trofei di Mario	0.96	1.91
Terme di Caracalla	5.12	5.27

Tab. 2 Ratios between the values at the top and on the basement
of the maximum effective and peak velocities

In Tab. 2 are reported the ratios between the maximum effective values and the peak values recorded at the top and those recorded on the basement of each monument. As we can see the values are very scattered.

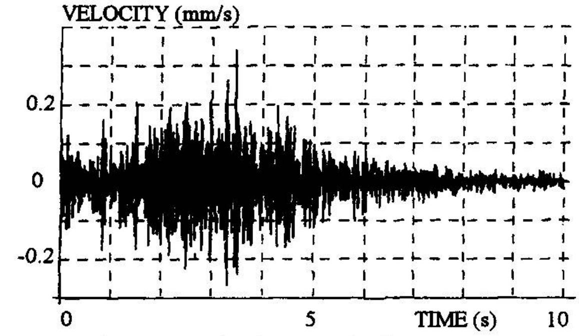

Fig. 1 Velocity on the basement
(Arco di Costantino)

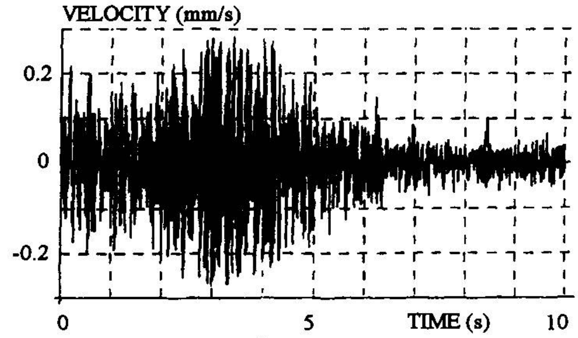

Fig. 2 Velocity at the top
(Arco di Costantino)

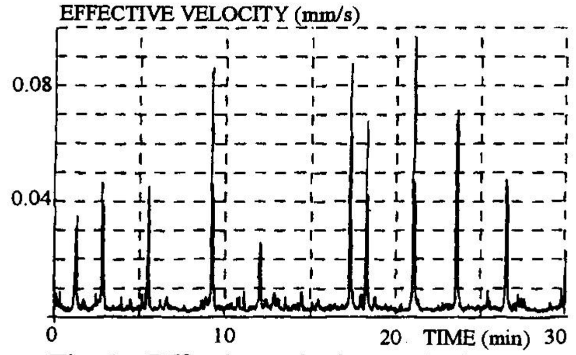

Fig. 3 Effective velocity on the basement

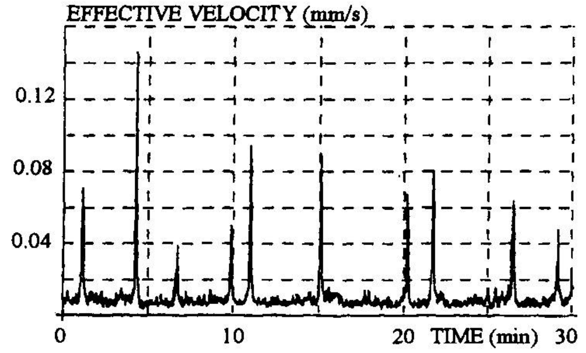

Fig. 4 Effective velocity at the top

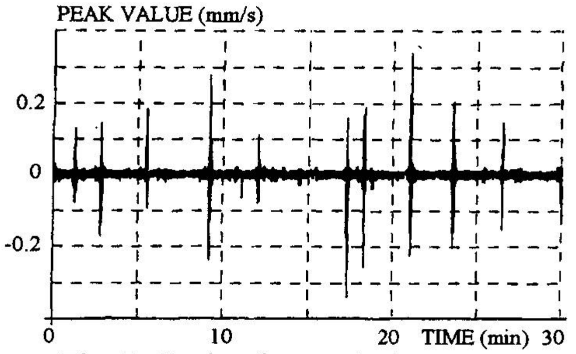

Fig. 5 Peak value on the basement

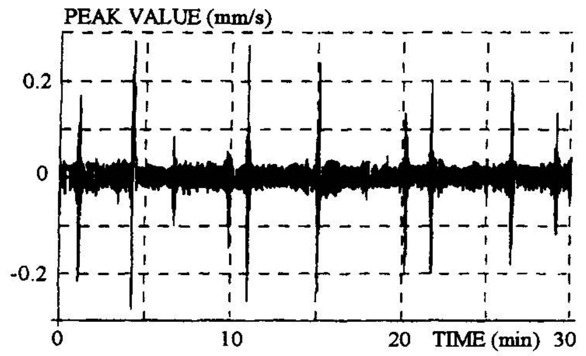

Fig. 6 Peak value at the top

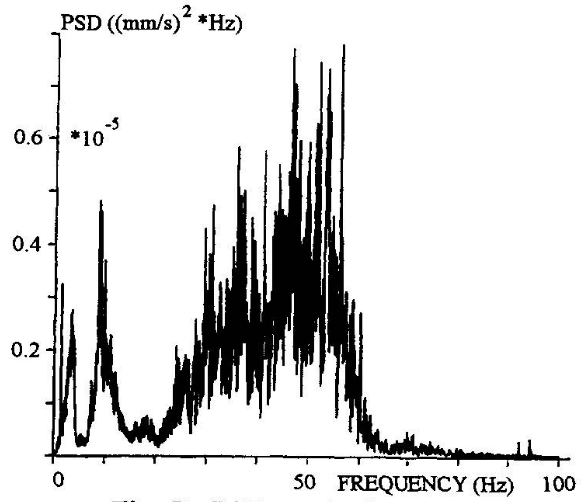

Fig. 7 PSD on the basement

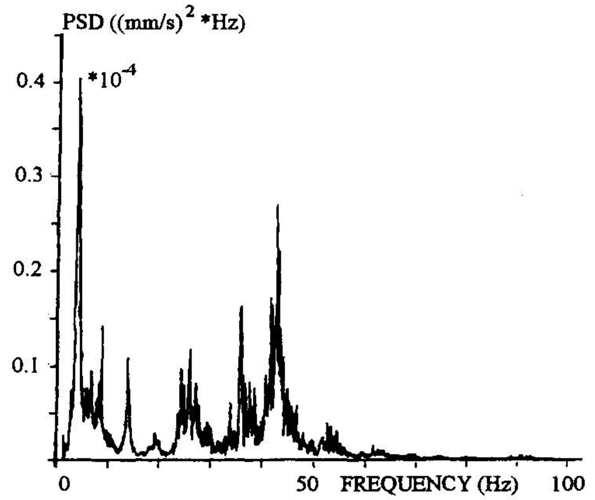

Fig. 8 PSD at the top

In some cases the difference between the effective velocities at the top and the basement is very low. Particularly vulnerable is the Tempio della Minerva Medica, for which the absolute peak value of the velocity at the top is very high (>2 mm/s). This monuments lies quite near to Termini Station (the main station in Rome) and another secondary railway runs just next to it.
The frequency content of the traffic induced vibrations is very wide, as we can see from the power spectral density of the signal recorded at the basement of the Arco di Costantino (Fig. 7). The power spectral density of the signal at the top of the monument is quite different (Fig. 8). In the first case high frequencies components are present in the signal, in the second one the peak at lower frequencies are more evident. This is obviously due to the filtering of the structure.

4. A CONTROL SYSTEM OF TRAFFIC INDUCED VIBRATIONS

To preserve a structure from the traffic induced vibrations an isolating system can be used. This kind of vibration control system is often adopted for the new constructions in seismic area. It is not very suitable in the case of existing structures.
An interesting solution was proposed by Colonnetti at the end of 50's to preserve Villa Farnesina, a building of the beginning of the sixteen century, from the effects of the heavy traffic [8]. The cartroad and not the building was isolated from the ground. The structure of the road was modified in order to peak up the wawes on their way to the soil under the road. This kind of solution offers the advantage to be effective for a large area including several constructions. For this reason it is very suitable for the central areas of the ancient cities.
In more detail, a rigid prestressed concrete gridwork on elastic rubber supports was built. The rubber supports were placed on a concrete slab laying on the road-bed. Concrete plates were placed on the grid and, over them, the bitumen paving.
The intervention, completed in 1970, interested a portion of the road of 64.52 m length, with a depth of 1.65 m. 1000 rubber supports were used, whose size was 22*12*3 (cm). Tipical bridge joints were utilized at the ends of the grid. The cost of the intervention was 50000 Italian Lire per square meter. According to the designer this solution guaranteed a reduction of the vibration amplitude of 80%.

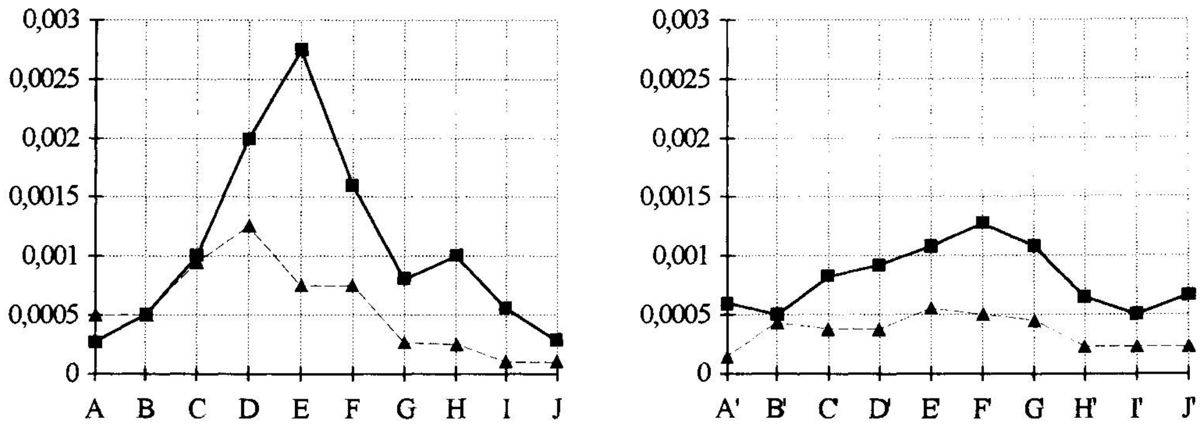

Fig. 9 Peak values of the ratio *a/g* recorded under and on the basement of Villa Farnesina

In Fig. 9 are shown the results of the drop impact tests carried out before the intervention in order to find the maximum amplitudes of the acceleration under the basement (triangles) and on the ground floor (squares) of the building and the zone on the road of maximum disturbance [8]. A to J were the position in which a mass of 70 Kg were dropped along the road on the pavement at the same side of the building. A' to J' were the corresponding locations on the other side of the road.

The distance between the first point A and the last one J was about 200 m. The drop impact tests simulated very well the effects due to the impact of a lorry weel in the holes in the cart-road.
This was the first time, in Europe and in the world, that a road was repared to preserve a monument from the traffic induced vibrations. A similar solution had already been used in Rome to preserve the Terme di Diocleziano from the vibrations induced by the traffic of the new Via Parigi [8].

5. CONCLUSIONS

Nowadays the effects due to the vehicular traffic are limited, because of the good quality of the pavings. Therefore our attention is focused on the effects of the vibrations induced by the passing of the trains. These can be very dangerous for structures already damaged and for old masonry structures. In fact, vibrations of small amplitude but characterized by a high number of cycles cause the reduction of the masonry strength due to the deterioration of the mortar and to its detachment from the bricks. Particularly vulnerable are the monumental buildings, bacause of the poor mortar used to build them.
The solution adopted for Villa Farnesina seams to be very interesting in the cases in which the railway is quite near to the structure and the vibrations induced by the trains are very dangerous, as in the case of the Tempio della Minerva Medica.
Anyway the monitoring of the construction is advisable in order to study the traffic induced vibrations in every specific case.

REFERENCES

1. BENDAT J.S., PIERSOL A.G., *Engineering application of correlation and spectral analysis*, John Wiley and Sons, 1980.
2. BONGIOVANNI G., CELEBI M., CLEMENTE P., The Flaminio Obelisk in Rome: vibrational characteristics as part of preservation efforts, *Earthquake Engineering and Structural Dynamics*, Vol. 19, No. 1, 1990.
3. CLEMENTE P., BONGIOVANNI G., Ambient Vibration Effects on the Colosseum, *Proc. IABSE Symposium "Structural Preservation of the Architectural Heritage"*, Rome, 1993.
4. CLEMENTE P., BONGIOVANNI G., MARZI C., La colonna Antonina in Roma: valutazione degli effetti delle vibrazioni ambientali, *Proc. 3rd Italian Workshop ASS.I.R.C.CO.*, Catania, 1988.
5. CLEMENTE P., RINALDIS D., BONGIOVANNI G., Dynamic characterization of the Tempio della Minerva Medica, *Proc. 10th European Conference on Earthquake Eng.*, Vienna, 1994.
6. EWINS D.J., *Modal testing: theory and practice*, Research Study Press, 1984.
7. ISMES, *Rilievo di vibrazioni indotte dal traffico metropolitano e/o autoveicolare su monumenti antichi della citta di Roma*, Report to ENEA, 1985.
8. RINALDIS D., CLEMENTE P., DONZELLI R., Analisi e controllo delle vibrazioni della Farnesina, *Proc. Workshop "Terremoti in Italia: previsione e prevenzione"*, Accademia Nazionale dei Lincei, Rome, 1994.