CORE Metadata, citation and similar papers at core.ac.uk
Provided by Missouri University of Science and Technology (Missouri S&T): Scholars' Mine

Missouri University of Science and Technology
Scholars' Mine

International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

1995 - Third International Conference on Recent Advances in Geotechnical Earthquake Engineering & Soil Dynamics

05 Apr 1995, 1:30 pm - 3:30 pm

Foundation Soil Influence on the Seismic Response of Piers

P. P. Diotallevi
University of Bologna, Italy

R. Poluzzi
University of Bologna, Italy

Follow this and additional works at: https://scholarsmine.mst.edu/icrageesd

Part of the Geotechnical Engineering Commons

Recommended Citation

Diotallevi, P. P. and Poluzzi, R., "Foundation Soil Influence on the Seismic Response of Piers" (1995). *International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics*. 7.
https://scholarsmine.mst.edu/icrageesd/03icrageesd/session05/7

This Article - Conference proceedings is brought to you for free and open access by Scholars' Mine. It has been accepted for inclusion in International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics by an authorized administrator of Scholars' Mine. This work is protected by U. S. Copyright Law. Unauthorized use including reproduction for redistribution requires the permission of the copyright holder. For more information, please contact scholarsmine@mst.edu.

Proceedings: Third International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, April 2–7, 1995, Volume I, St. Louis, Missouri

Foundation Soil Influence on the Seismic Response of Piers

Paper No. 5.19

P.P. Diotallevi
Professor of Earthquake Engineering, University of Bologna, Italy

R. Poluzzi
Professor of Construction Engineering, University of Bologna, Italy

SYNOPSIS Significant experimental dynamic tests by vibrodyne were conducted on single piers of a motorway near Livorno (Italy). Tests were conducted on structures similar to each other but founded on two different type of soils (underconsolidated silts below the water table and overconsolidated clays) and very different dynamic responses were found in terms of damping and natural frequencies. This effect was particularly evident for single piles proving the importance of soil characteristics upon the dynamic response of the structure. It is refere also a numerical investigation about the behavior of identical structures founded on different soils and subjected to the same seismic input.

INTRODUCTION

A dynamic experiment, carried out using forced vibrations with vibrodyne, on similar bridge piles embedded in soil with very different geotechnical characteristics, revealed marked differences in the responses, correlated to soil-structure interaction.

First of all, designers of these structures will be interested to learn about these differences, as it should be pointed out that the current hypothesis of "piles perfectly embedded in their bases" should only be considered reasonably reliable in the case of compact soils. Even under these circumstances in fact the structure vibration periods are affected, although in an insignificant manner, by the soil deformability.

On the basis of studies carried out and subsequently illustrated in detail, it can therefore be stated, that in the event of soft soils the importance of the role played by the soil is not just that it modifies the period of the structure but it also reveals soil-structure patterns with different energy dissipation possibilities, which appear to depend on the dynamic excitation frequency.

It is known that a seismic event transmits the actions to the structure through the soil, and therefore what happens during these events is different from the excitation of the structure with a vibrodyne. However it is thought that this type of investigation may provide useful indications for design, that is if it makes it possible to identify appropriate behaviour models.

In this note, besides reporting the investigations made and the most significant results, an attempt was made, using an appropriate numeric model operating in the domain of the frequencies, to work back from the results mentioned to the effects that known accelerograms can produce on similar piles embedded in different soils[1].

DYNAMIC EXPERIMENTS ON PILES

The experiments were carried out on piles in some viaducts on the Livorno-Civitavecchia motorway in the Livorno-Rosignano section in Tuscany (Italy). The piles, although different in shape, but similar in height, rigidity and geometry of the foundation piling, are found in sites with quite different geotechnical features. For the Gonnellino viaduct, the soil is quite compact, whereas for the Coltano viaduct, the soil is a recent deposit, consisting of poorly consolidated clayey silt (at least for the first 20-30 metres) and in the water-bed. The experiment was carried out using a 20 kN vibrodyne (generating sinusoidal forces) fitted with variable angle masses, able to operate in the frequency interval of 0 to 25 Hz and positioned on the top of the piles before the framework was built. The effects on the piles were measured with accelerometers placed horizontally at the top and at different heights on the piles.

Processing of the measurements made it possible to construct transfer functions a/F (a = amplitude of the frequency acceleration component equal to the excitation frequency; F = amplitude of the force applied by the vibrodyne) obtained for the piles on the different viaducts. These were markedly different for the piles on the Gonnellino (fig.1) viaduct (and other viaducts founded on soils having similar characteristics) to those of the Coltano viaduct (fig.2).

It should be stressed that the unusual trend of the a/F function for the Coltano pile was perfectly reproduced when the test was repeated using the same method.

It is evident that in the first viaduct the foundation on piles, embedded in markedly more compact soil, show a fairly rigid restraint with a poor dissipation which however considerably attenuates the frequency of the fundamental pile vibration mode on the rigid base. For the other viaduct, where the piles are embedded in a saturated soil of very poor consistency, the more deformable restraint shows, in terms of the dynamic response, features which vary much more markedly with the frequency than in the example of the first two viaducts.

---

[1] The writers admit that the same earthquake would produce different accelerograms on the surface of soils of different nature even if all the other circumstances (distance from the epicentre, etc.) are the same: the authors believe however that this investigation was worth examining.

The calculations and evaluations below are based on the a/F spectra obtained with the accelerometers on the top of the piles. It should however be noted that the readings, with the other accelerometers at different heights on the piles, indicated that at the higher frequencies the pile curvature is accentuated, with a marked attenuation of the displacement at the base, as compared with the deformations which appear with lower frequencies.

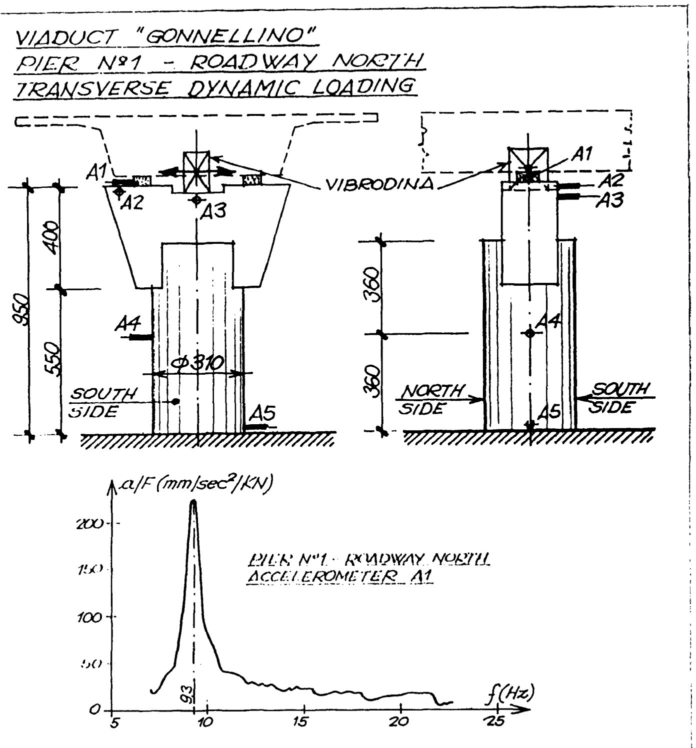


Fig. 1

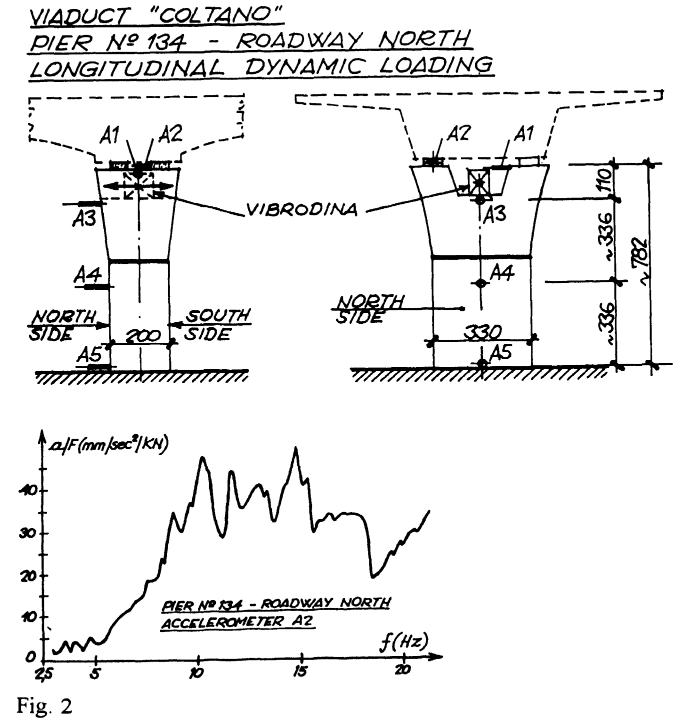


Fig. 2

Although this last aspect is quite interesting as regards the dynamic interaction phenomena observed between structure and soil, it does not appear to be determinant for a first purpose of this study, and for this reason the following assessments are based merely on the summit accelerometers.

THE RESPONSE OF DIFFERENT STRUCTURES TO SEISMIC EVENTS

To rapidly reach results which highlight the difference in the responses to the same earthquake, the behaviour of the piles can be represented as that of elementary oscillators with viscous damping. To be more precise, the piles of the first viaduct can be liken to a simple oscillator, while the Coltano viaduct, on the basis of the a/F function patterns, appears more like several elementary oscillators which are significantly excited in successive frequency fields.

Adopting this equivalence scheme in a dynamic field, it was possible to calculate from the known accelerograms of several earthquakes, the effects of these earthquakes on the piles considered, in terms of oscillator movement and therefore, within the sphere of the approximations assumed, the summit of the pile from whose movement it was possible to calculate the characteristics of the equivalent oscillator.

To be more precise, the deflection pattern was determined as a function of time

$$x(t) = \sum \frac{F_0}{K} f_A \sin(\omega t + \phi + \psi) \qquad (1)$$

the sum being extended to all the ω frequencies which make up the accelerogram of the earthquake considered, taking into account the two phase components (ψ = phase relative to the earthquake component with a frequency ω and ϕ = phase shift between the excitation pulsation and the response of the individual oscillator).

In the same (1) for each individual oscillator:

$$f_A = \frac{1}{\sqrt{\left(1 - \frac{\omega^2}{\omega_n^2}\right)^2 + 4\nu \frac{\omega^2}{\omega_n^2}}}$$

where ω_n is natural circular frequency of oscillator,
ν is damping ratio,

$$\phi = \text{arc tg } 2\ \nu \frac{\frac{\omega}{\omega_n}}{1 - \frac{\omega^2}{\omega_n^2}},$$

K is the stifness of equivalent oscillator,

$\frac{F_0}{K}$ is elastic (static) displacement

where $F_0 = m * a$ where m is the oscillator mass and a is the amplitude of the frequency component ω of the excitation accelerogram.

The magnitudes ω_n, K, ν characteristic of the oscillator or the oscillators, which must describe the behaviour of the pile, are obtained from the experimental curves a/F and precisely:

- ω_n is the circular frequency $2\pi f$ has been assumed in correspondence with the significant peak of frequency (f) with diagram a/F;
- the damping ratio ν was obtained from the a/F pattern by "half power method"[Clough];
- since the pulsation ω_n is known and the response of the structure in terms of acceleration and therefore displacement, and the amplitude of the force supplied by the vibrodyne, the rigidity was calculated as $K = \frac{F_0}{x}\frac{1}{2\nu}$ (x = displacement);
- finally the mass was determined as $m = \frac{K}{\omega_n^2}$.

For the viaduct "Gonnellino" the determination of the parameters to be inserted in (1) was therefore simple and univocal; for the viaduct Coltano the scheme for the determination of the oscillator parameters is identical, but several oscillators were identified as shown in fig. 3 and each of these was considered active in the significant part of the peak characterizing it covering in any case, with one oscillator at a time, the entire field of frequencies explored with the experiment.

RESULTS

The calculation was made for four earthquakes thought to be significant and for which accelerograms on the ground were available and to be precise: El Centro, Tolmezzo, Parkfield and Petrovak.

Obviously, each accelerogram on the ground was previously described in the domain of the frequencies with the known analysis procedures of Fourier(fig.4). Then with a numeric program the displacements due to the components of all the frequencies were calculated and accumulated and the results, in terms of the pattern over time, are shown in the graphs.

A first comparison between the results immediately revealed that the piles in the more rigid soil (Gonnellino and others in similar soils) showed much more limited displacements than those situated in the recently deposited soil (Coltano). The great differences can be mainly attributed to the different response of the piles to the earthquake components with the lower frequencies; at these frequencies the piles examined, not very high, fairly rigid if embedded in compact soil were clearly less sensitive. This was different for "Coltano" where the piles were shown to be more vulnerable to the earthquake.

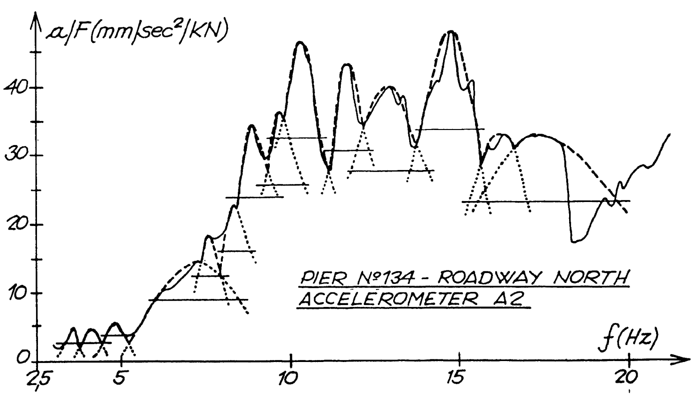


Fig. 3

Given the clear difference in the results it was thought to be useful, for each earthquake considered, to compare directly the diagrams of the displacements over time obtained for the Gonnellino viaduct and for the Coltano viaduct. The diagram of displacements is shown in figures 5, 6, 7, and 8, while earthquake acceleration spectra are displayed in fig.4.

CONCLUSIONS AND PROSPECTS FOR FURTHER INVESTIGATIONS

On the basis of the results obtained, both clear and significant, it is possible to make various important observations:

- the maximum displacements calculated for the different piles, compared in the graphs, also differ in magnitude; it is true that these differences appear in reality for quite different pile deflection patterns and are markedly influenced by the major yielding of the basic restraint for the piles in the Coltano viaduct, however, the differences remain very considerable and match what is already known, i.e. that the consequences of earthquakes are generally aggravated in the presence of soft soil.
- more detailed information could probably be obtained by assuming for the piles, with their relative foundations, more elaborate structural models (e.g. using F.E.M.) and subjecting these models to the same seismic inputs assumed here.
- It should be underlined that, at least for the earthquakes examined, the determinant seismic components with the major amplitudes are those with low frequencies (approximately 2-5 Hz). At least for the earthquakes mentioned and for short piers as that tested, on the basis of this numerical results, it would appear to be advisable to have more rigid structures, characterized by high frequencies, since these are far from the dominating frequencies of the different earthquakes examined.

The above obviously applies to the piles examined, and before the construction of the framework, or at least for structures with similar dynamic characteristics.

For the bridge as a whole or for more slender piers, different situations arise, and they generally have lower frequencies. The results described here may however provide useful indications for designing and identifying the characteristics of eventual seismic isolation devices.

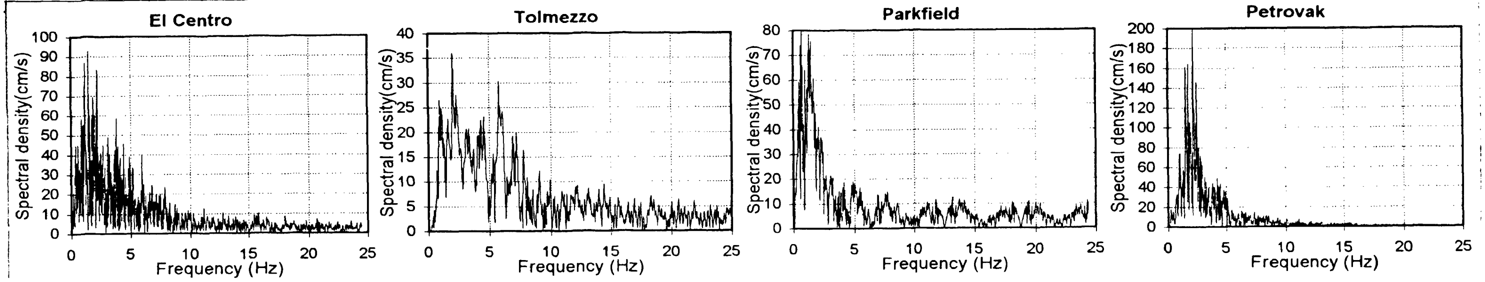
REFERENCES

Clough R.W., Penzien J., "Dynamics of structures", McGraw-Hill, 1975.

Bata M., Plachy V., "Analysis of dynamics effects on engineering structures", SNTL, Praga, 1987.

Alessi R., Diotallevi P.P., Poluzzi R., Guiducci M.F., Radogna E.F., Calcerano G., Collari B., Malisardi L., "Sperimentazione dinamica ed identificazione strutturale: premesse teoriche, tecniche operative. Esempi di applicazioni ad opere infrastrutturali", Atti delle giornate AICAP '93, Pisa, Giugno 1993.

Carrubba P., Diotallevi P.P., Maugeri M., Poluzzi R., "Site condition effects on the dynamic behaviour of viaduct piers", 10th European conference of earthquake engineering, Vienna, Agosto 1994.

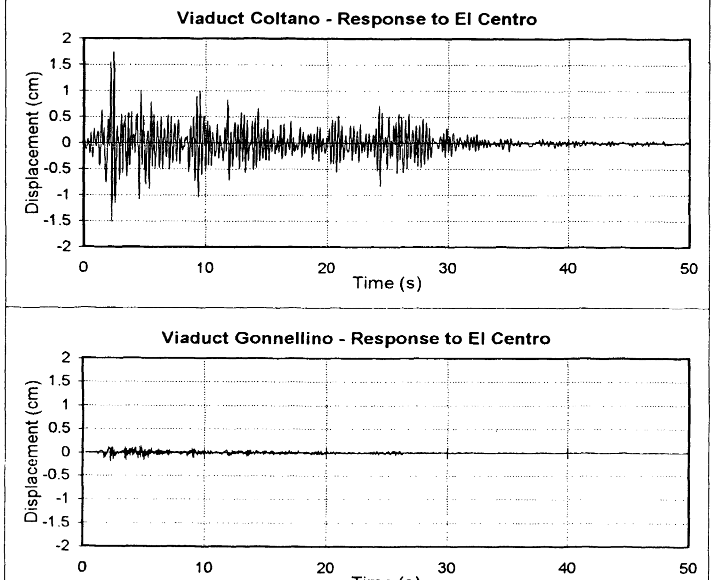

El Centro

Tolmezzo

Parkfield

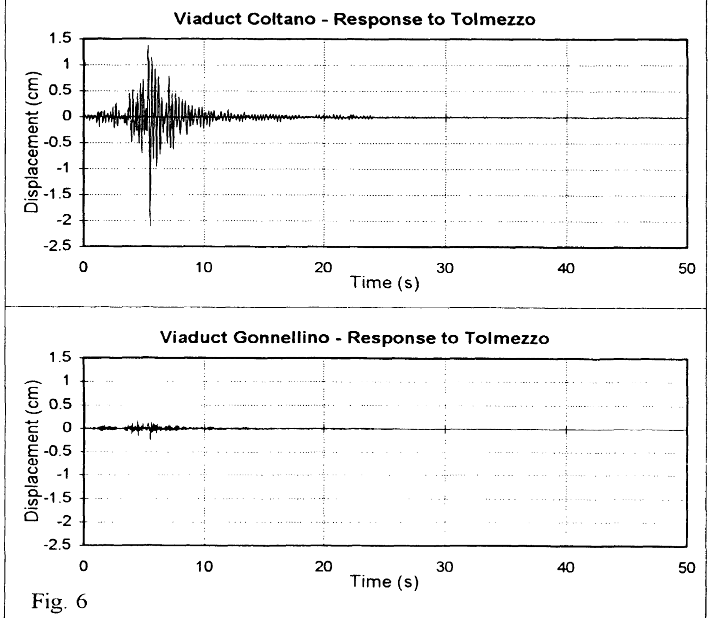
Petrovak

Fig. 4


Viaduct Coltano - Response to El Centro

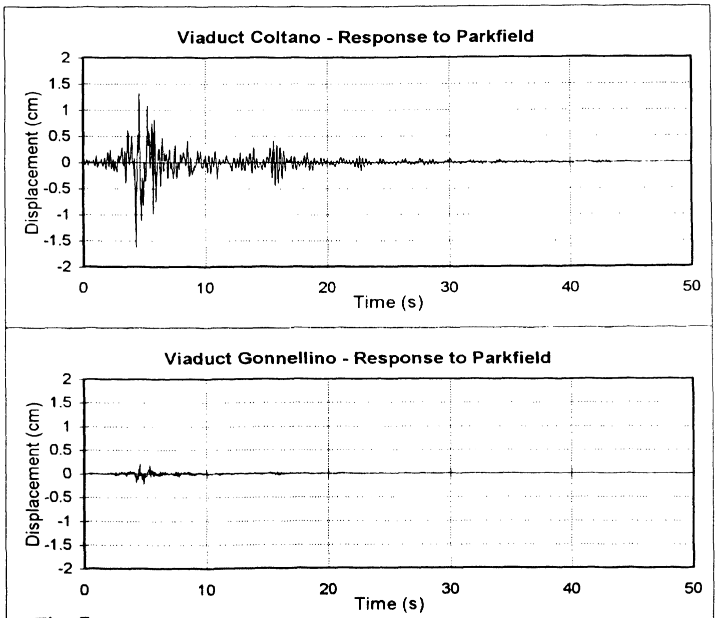
Viaduct Gonnellino - Response to El Centro

Fig. 5


Viaduct Coltano - Response to Tolmezzo

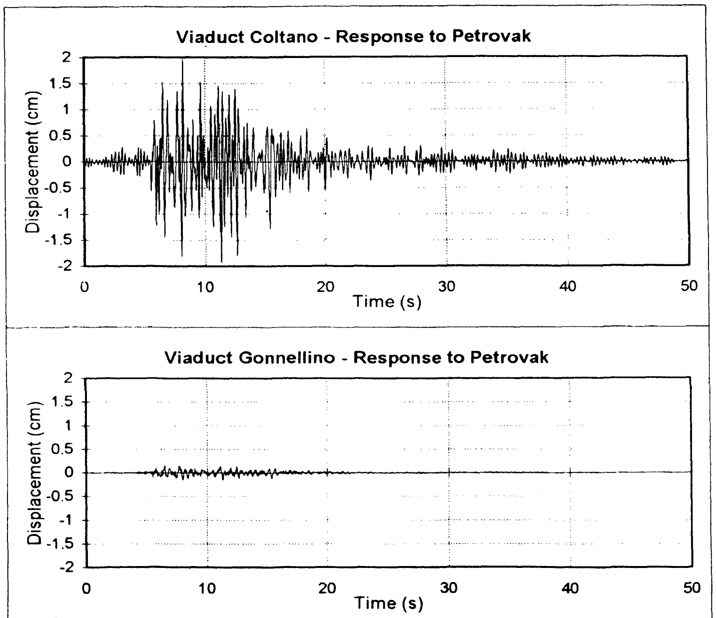
Viaduct Gonnellino - Response to Tolmezzo

Fig. 6


Viaduct Coltano - Response to Parkfield

Viaduct Gonnellino - Response to Parkfield

Fig. 7


Viaduct Coltano - Response to Petrovak

Viaduct Gonnellino - Response to Petrovak

Fig. 8