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Monitoring System for Bridges of the Livorno-Cecina Highway

Système de surveillance des ponts de l'autoroute Livorno-Cecina

Das Brückenüberwachungssystem der Autobahn Livorno-Cecina

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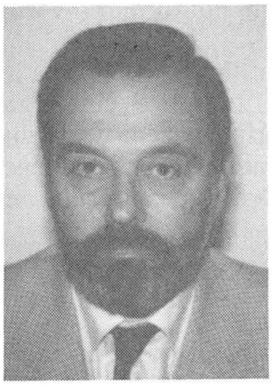

Alberto Parducci, born in 1934, received his civil engineering degree at the University of Rome. He has been involved in aseismic design of bridge structures. His research has involved seismic isolation and patented isolating devices.

SUMMARY

The monitoring project designed for the field control of the bridges of the new Livorno-Cecina highway is illustrated and the main targets are discussed. The project provides systems for automatic permanent measuring, periodic surveying, and seismic recording. Special softwares have been designed and developed for collecting and managing the recorded data. The corresponding procedures are discussed and typical examples are presented.

RÉSUMÉ

Le projet de surveillance et de contrôle des ponts de la nouvelle autoroute Livorno-Cecina est présenté et les principaux objectifs sont discutés. Le projet prévoit des systèmes de mesures permanentes automatiques, pour le contrôle périodique et pour l'enregistrement sismique. Un logiciel spécial a été développé pour la récolte et la gestion des données enregistrées. Les procédures correspondantes sont discutées et quelques exemples typiques sont présentés.

ZUSAMMENFASSUNG

Das für die ständige Bauwerkskontrolle der neuen Autobahn Livorno-Cecina entworfene, fest eingebaute Ueberwachungssystem wird vorgestellt und seine hauptsächlichen Zielsetzungen werden erläutert. Das System garantiert ständige Messungen, Überwachung in regelmäßigen Zeitabständen und Aufzeichnung der Erdbebendaten. Zur Aufnahme und Verarbeitung der aufgezeichneten Daten wurden spezielle Softwareprogramme ausgearbeitet. Die entsprechenden Abläufe werden besprochen und typische Beispiele vorgestellt.

1. INTRODUCTION

Technical evolution and industrialization leads to building complex and sophisticated structures exploiting the extreme resistance of materials. Moreover, in bridge constructions severe problems of durability occur [1,2], so that the frequency of maintenance works increases involving higher repair costs and uneasiness to the users. Thus, the need of planning and designing these works on the basis of organized instrumental control systems has also increased. In the past, little attention was paid to the knowledge of the actual behaviour of the structures during their life time. Only in the last few years the importance of the problem has been recognized and the design of control systems began to be performed together with the structural design. Nowadays, the experience of observers can be validated by instrumental measurements and through direct or indirect tests [3,4], whose reliability derives from the experience developed with their use. At present, the practice for the interpretation of the results is advanced enough, but further investigations must still be performed.

To improve the knowledge of these problems a monitoring project has been designed and applied to the main bridges of the new Livorno-Cecina highway, built in a seismic zone of Tuscany, in central Italy [5]. In 1994 the monitoring system was delivered to the tender SAT Company. Considering the point of view of the structural designers the general organization of the project, the acquisition and management software and some typical results are illustrated in the present paper.

2. THE MONITORED STRUCTURES

The bridges consist of two separate structures m 12.25 wide, one for each carriage-way. The decks were built as continuous multi-span segments of prestressed concrete structures. Different structural configurations and constructive systems were used [6]. All the bridges were provided with seismic isolation systems based on the elasto-plastic behaviour of horizontal restraints [7]. Also special connecting devices consistent with the requirements of the continuity of structures were applied.

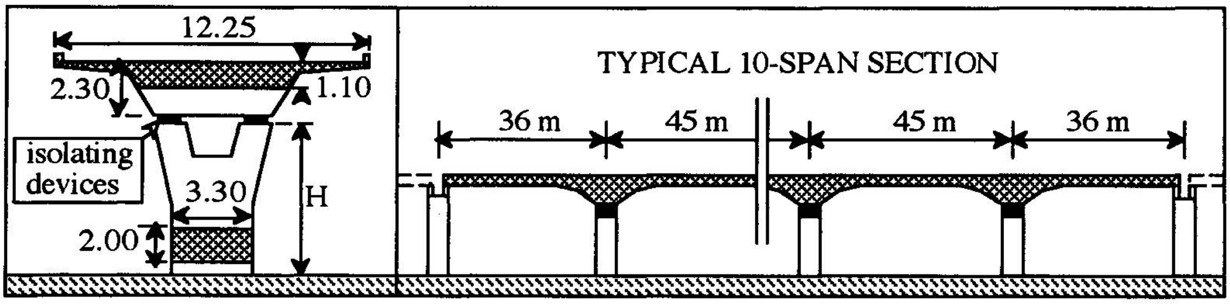

Fig. 1 - General lay-out of the "Coltano" bridge

The "Coltano" bridge, m 9860 long, is the most important and complex. The typical segment, spanning over 10 bays, is 432 meters long (Fig. 1). It was built using a cast-in-situ advancing procedure. Its particular configuration consists in a gross section of variable thickness (m 2.30 over the supports to only m 1.10 in mid-span) with large lateral cantilevers. The decks of the other bridges are all made as boxed structures. The "Gonnellino" bridge has a single continuous segment m 660 long; each span was built connecting two longitudinal precast half-elements. The "Savalano" bridge was built using this same procedure; its total length of m 1860 is divided into three continuous sections. The total length of the "Morra" bridge (m 856) is divided into two continuous segments; the boxed deck was built using an advancing prestressed procedure. The "Poggio Iberna" bridge is m 2518 long and is divided into five continuous segments; it was built by launching entire precast spans connected in situ.

3. THE MONITORING PROJECT

Different purposes were considered designing the monitoring system, including the recording of the effects of environmental conditions, the actual in-situ evolution of the characteristics of the structural materials, the control of deformations and displacements of structural elements (bearing and joint displacements) and the response of the structures to seismic attacks. Therefore the monitoring design, based on a permanent measuring system and periodic surveying operations, was directed to control the following factors:

- environmental data (temperature and humidity);
- evolution of the mechanical characteristics of the concrete;
- displacement of significant elements of the structures (bearing and joints) due to the evolution of the mechanical characteristics of the concrete and to environmental factors;
- local deformation in significant points of the structures;
- structural displacements due to soil settlements;
- response of the structures to seismic attacks.

Three recording stages have been foreseen. The first one was carried out during the final inspection of the works in 1993. In the second stage, during the following year, the data acquisition and management "ADaMo" software was developed and the general procedures were tested. At present, the normal monitoring survey is being carried out by SAT.

The permanent measuring systems consist of strain-gauges (±2500 μ/m), put into the concrete during the construction which record local deformations, thermometers (-50+150°C) and hygrometers (0÷100%HR) which record the near-by external data and those in the boxed structures (Fig. 10). Starting the "Indaco" automatic procedure the instrumental data are digitalized and recorded in peripheral acquisition systems. Moreover, the bearings displacements and the relative deformations of the expansion joints between continuous sections can be measured through digital devices.

The periodic surveying system consists in the following activities:

- topographic levelling of the vertical configurations of decks and foundations;
- dynamic and static load tests of typical spans;
- direct and indirect measurements of the resistance of the concrete.

The concrete survey is performed using cubic and cylindrical crushing tests, together with ultrasonic, rebound, pull-out and penetration tests. To avoid taking out samples from the bridges, sets of standard cubic concrete samples and large concrete blocks were fitted up during the construction works and laid down near the structure, so that cylindrical samples can be driven from the blocks.

The seismic surveying system consists of strong-motion recorders of the three response components (±2g, 0.02÷2000 Hz, post and pre-trigger of 10 s) in three points of typical spans: foundation, top of the column, deck structure. They start to run when the horizontal acceleration of a foundation device exceeds 0.02g. A special procedure avoids that loud peals of thunder start up the system.

Particular tests have been also performed during the construction works. Significant is the result achieved from a dynamic test carried out before the construction of the decks on a single pier of the "Coltano" bridge. In spite of the rigidity of the foundations, 80% of the longitudinal flexibility derived from the foundation's deformations and only 20% from the column's flexibility (Fig.2). This result emphasizes the importance of the foundation flexibility on the estimation of the natural periods.

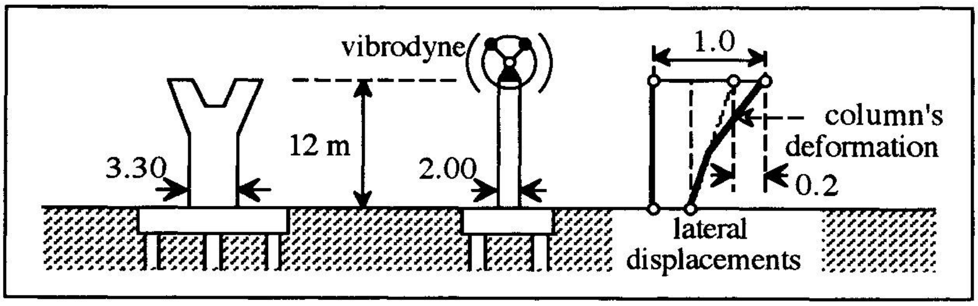

Fig. 2 - Dynamic test of a pier before the construction of the deck structure

4. THE DATA-BASE "ADaMo"

The field measurements are collected by the data-base "ADaMo" (Archiviazione Dati di Monitoraggio) which allows their management, showing their evolution and possible correlations. In order to accept different measurement procedures, the storage system uses uni-dimensional data containers ("instruments") collecting data with respect to time and location: the "time instruments" contain the evolution of data in time (example: the automatically recorded data); the "location instruments" contain the data recorded by different devices at the same time (example: the bearing displacements). The sets of data are then considered as bi-dimensional time-location matrixes.

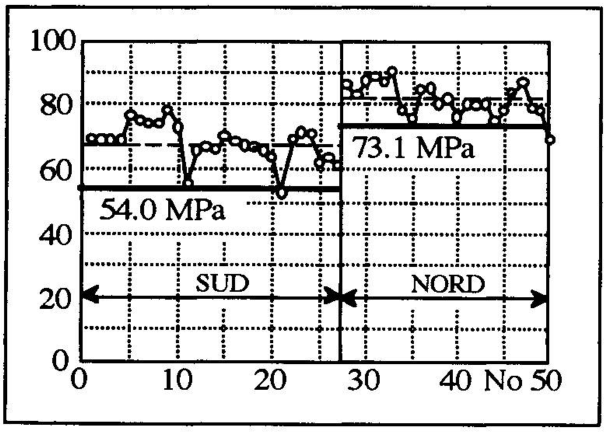

Fig. 3 - Standard resistances of cubic samples

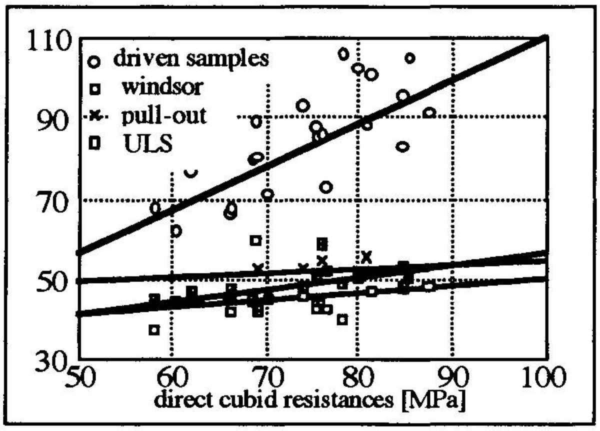

Fig. 4 - Correlation analyses

Some results are shown in Fig. 3, where the standard resistances of one year old concrete cubes are plotted, and in Fig. 4, where typical correlation are represented. The data of static tests are also managed by "ADaMo". Fig. 5 illustrates the representation system. In order to compare the results of tests carried out in different times, the measured displacements are plotted versus the theoretic values calculated from the real positions and intensities of each load.

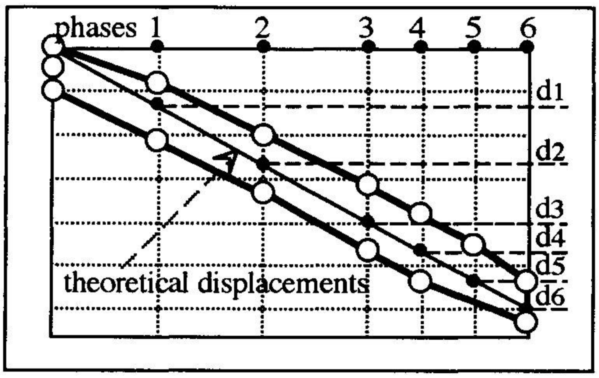

Fig. 5 - Typical result of a load test

Examples of the typical records of "ADaMo" are reproduced in Figs. 6 and 7. The former shows the bearing displacements and the deformations of the nearby expansion joint, plotted versus the time; the latter shows the correlation between two recorded data (longitudinal mid-span deformations and temperature gradient between top and bottom of a boxed section). Finally, the general scheme of the software is sketched in Figs. 8 and 9, while the locations of the permanent monitoring devices are illustrated in Fig. 10.

ACKNOWLEDGEMENTS

SOTECNI (Società Tecnica Internazionale) designed the Livorno-Cecina section of the Livorno-Civitavecchia highway for SAT (Società Autostrada Tirrenica). A. Parducci was the scientific consultant of Sotecni for the organization of the monitoring project. ISMES fitted out the permanent monitoring instruments and the automatic recording system. The authors of this paper, consultants of TEKNO-IN, designed "ADaMo", the acquisition and management data monitoring software.

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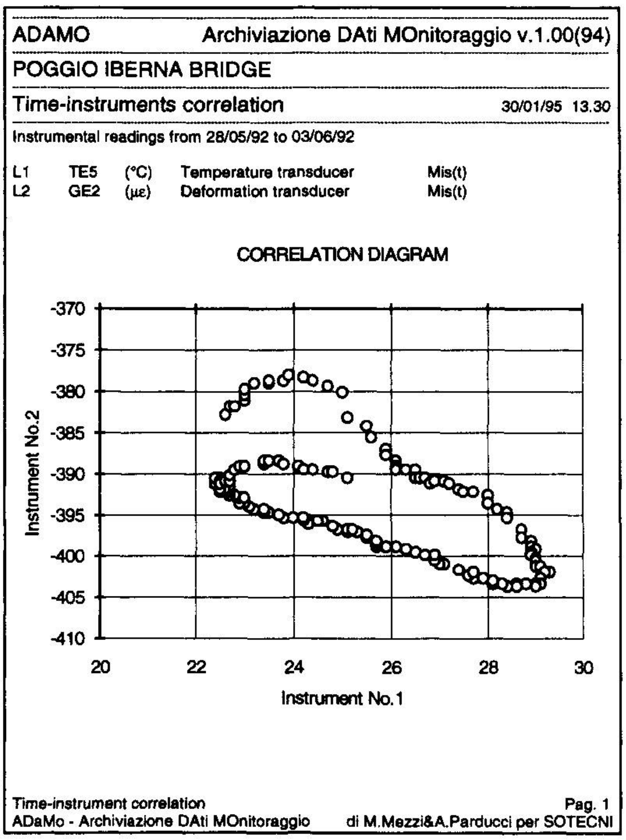


Fig.6 Sample of "ADaMo" report

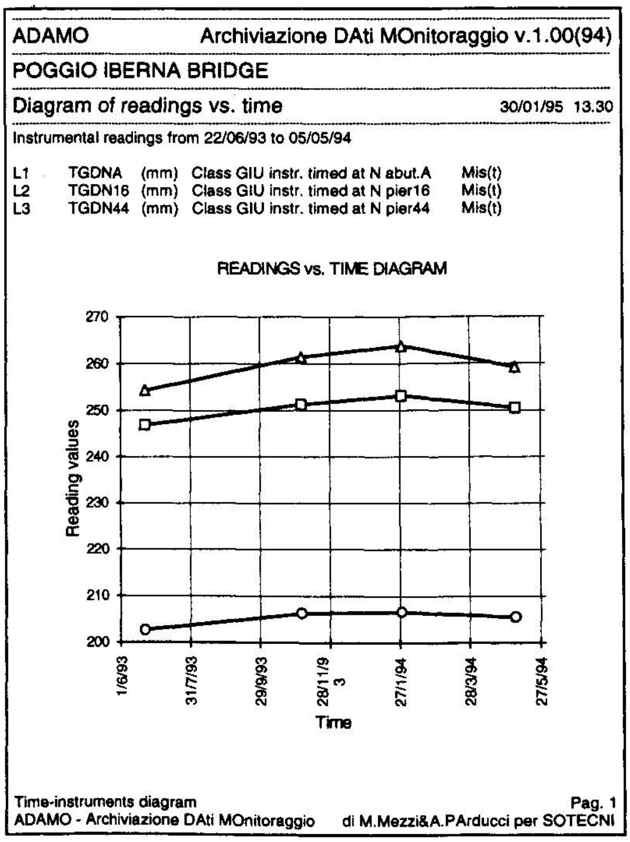


Fig.7 Sample of "ADaMo" report

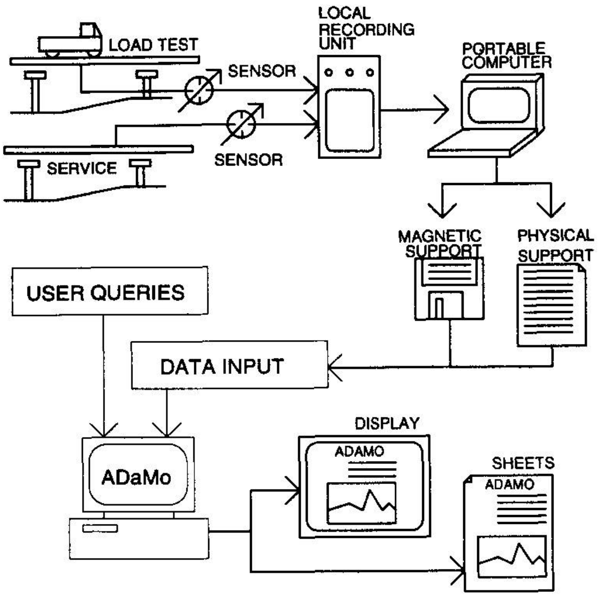


Fig.8 General scheme of the monitoring system

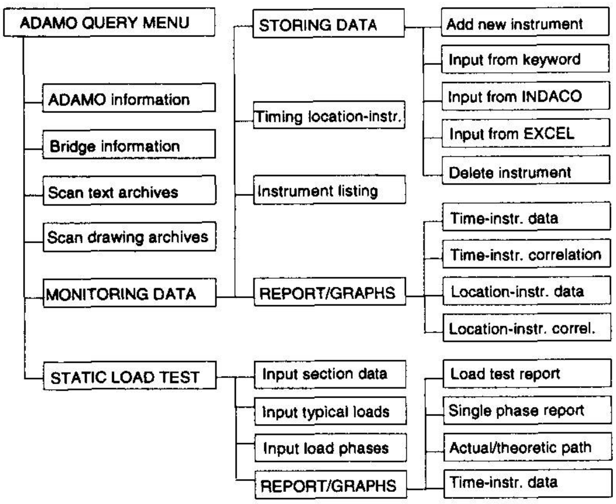
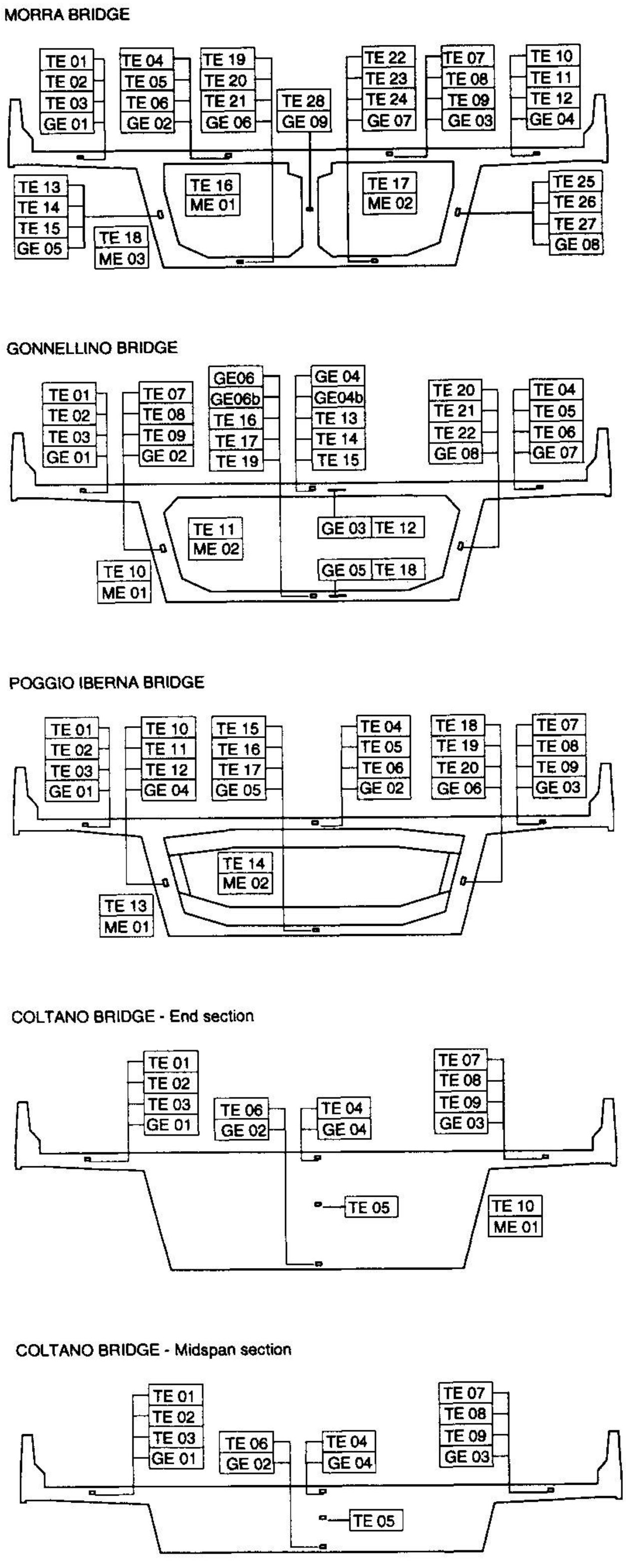


Fig.9 "ADaMo" query structure



Transducers: TE=temperature, ME=humidity, GE=deformation

Fig.10 Locations of the permanent monitoring devices