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Evaluation of Structural Behaviour by In-Situ Dynamic Tests

Evaluation du comportement structural au moyen d'essais dynamiques in-situ

Bewertung des Tragwerkverhaltens bei dynamischen In-situ-Versuchen

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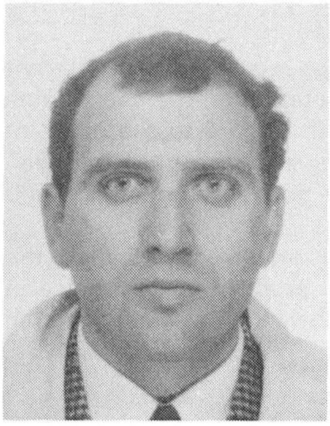

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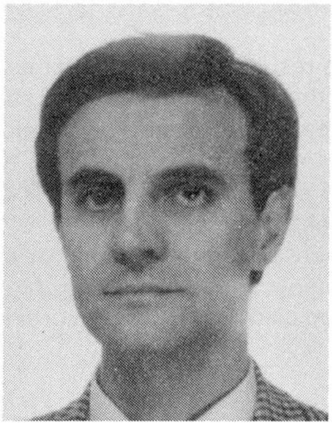

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SUMMARY

This paper reports the comparisons between the results of in-situ dynamic tests, carried out on mixed reinforced concrete and steel structures, and the results of the related numerical models. The study is directed towards verifying the possibility of evaluation of some parameters caracterizing the structural behaviour at service load levels. This article summarises the experimental and numerical work undertaken at the University of Trento, as part of a research project entitled «Serviceability Deflections and Displacements in Steel Framed Structures».

RESUME

Dans ce rapport on a exposé les résultats des essais dynamiques in-situ, exécutés sur des structures de bâtiments, en béton armé et en acier, comparés aux résultats des modèles numériques correspondants. On a cherché à évaluer certains des paramètres qui caractérisent le comportement structural pour des charges réelles. Ce rapport résume les recherches expérimentales et numériques menées à l'Université de Trento, faisant partie d'un projet de recherche «Serviceability Deflections and Displacements in Steel Framed Structures».

ZUSAMMENFASSUNG

Der Beitrag enthält einen Vergleich zwischen den Ergebnissen von dynamischen In-situ-Versuchen und den entsprechenden numerischen Modellen. Zweck der Studie ist die Untersuchung der Bewertungsmöglichkeit einiger Parameter, die das Tragverhalten unter Nutzlast charakterisieren. Es werden hier die experimentellen und numerischen Untersuchungen des Forschungsprojekts «Serviceability Deflections and Displacements in Steel Framed Structures» zusammengefasst, die an der Universität Trient durchgeführt wurden.

1. INTRODUCTION

The capability of evaluating the actual structural behaviour of ancient [1], old and new buildings is a significant research item particularly referring to serviceability limit states. Furthermore, the evaluation of the influence of internal and boundary connections on the global behaviour is relevant in order to establish simplified design and optimization criteria for the checks at service load levels.
To this purpose a three-part programme of research, focusing on static deflections of steel framed buildings, funded by the European Coal and Steel Community (ECSC), was started in late 1990.
It comprised:
- Investigation of the in-service performance of steel buildings (TNO-Bouw);
- Review of existing code requirements and their basis (University of Nottingham);
- Numerical studies and considerations on design models and in-situ dynamic tests on steel and steel-concrete buildings (University of Trento).

A report [2] giving the findings of each aspect of the work has been presented to ECSC. The content of this paper is complemented by three other papers at this conference which deal with the other topics of the research [3, 4 and 5].

This paper reports some results of in-situ dynamic tests and numerical analyses regarding two different types of new buildings, the first one made with steel columns and steel-concrete floors, the second one entirely realized with steel. Two kinds of dynamic exciter have been used with regard to the different masses of the two buildings. Physical results (in terms of acceleration and power spectrum) have been compared with those of some numerical models obtained assuming different boundary conditions and internal continuity between the elements.
Conclusions are drawn concerning the capability of in-situ dynamic test methods to correctly estimate the structural behaviour at service load levels; on the basis of the test results the problem of the choice of test methodologies will be discuss, in order to provide meaningfully results for the evaluation of the actual behaviour.

2. INVESTIGATED STRUCTURES

2.1 The mixed structure

The first structure investigated, briefly described in figure 1, is a part of the extension of passengers aerostation of Milan-Linate Airport.
It is essentially a rectangular mixed r.c.-steel building with a basement and one above-ground floor.
The floor thicknesses are of 0.45 and of 0.50 m respectively for spans of 8 and 12 m. The floor structure consists of reinforced concrete predalles with load-reducing polystyrene blocks, supported by in pairs 8 m span steel beams which are included into the final layer of concrete (see Sec. A-A, Fig.1). The beams have no continuous steel reinforcement at the column lines.

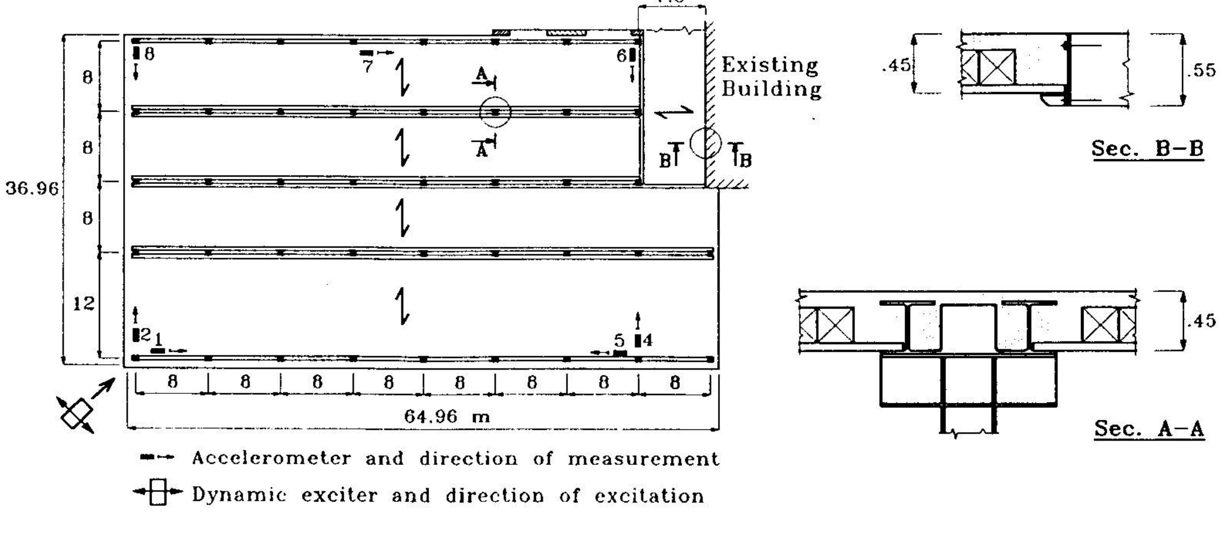


Fig. 1 - Mixed RC-steel structure: roof floor plan and location of instruments

2.2 The steel structure

The second structure investigated, briefly described in figure 2, is a part of the roofing steel structure of the extension of passengers aerostation of Milan-Linate Airport.
The roofing structure, based on the r.c.-steel part of the buiding, is realized with longitudinal HE 300 B and IPE 400 main beams, for the 8 m spans, and with welded beams for the 12 m spans; the transversal secondary beams are 8 m long IPE 270. The columns are realized with HE 240 A and HE 400 B sections. The horizontal deflections are limited by nominally pinned portal frames in the transversal plane, realized with HE 260 B beams and welded columns, and by a brick wall along the A alignement.
In the roof plane a cross-bracing system, realized with 28 mm diameter steel bars, provides the necessary in-plane stiffness (see Fig. 2).
The roofing is made by profiled steel sheeting riveted to the structure.

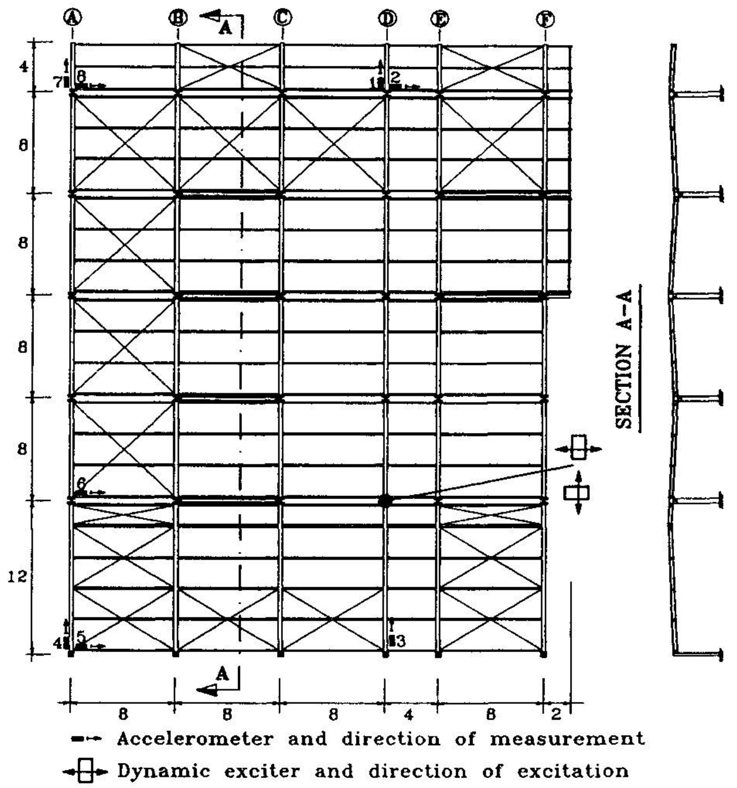


Fig. 2 - Steel roofing structure: plan and location of instruments

3. NUMERICAL ANALYSES AT SERVICE LOADS

3.1 The mixed structure model

Finite element models, entirely realized with beam type elements only, have been set up to evaluate the fundamental vibration frequencies of the structure as a whole. Numerical analyses have been carried out for different internal continuity degrees between the elements. The following cases are here reported:

- structure with base pinned columns and full continuity for all internal joints;
- structure with base fixed-end columns and pinned beams;
- as the previous but with full continuity for all internal joints.

Case #	Fundamental Frequencies [Hz]		
	Mode 1	Mode 2	Mode 3
1	1.87	4.37	4.96
2	2.10	4.18	4.79
3	3.48	5.08	5.81

Table 1

The three fundamental free vibration frequencies for the described cases are reported in table 1; the three modes are the same for the three cases considered and are horizontal vibrations.

3.2 The steel roofing structure model

A finite element model, which also make use of beam elements only, has been adopted for the numerical study of the steel roofing structure.
In the analyses the full continuity has been considered at the top end of the columns, at the ends of the main longitudinal beams and at the ends of beams of pinned portal frames. On the contrary the secondary beams have been considered as simply supported.
The numerical analyses have been carried out for three different cases:

- with base pinned columns;
- with base pinned columns and with the contributions of the brick wall and of the steel sheeting;
- as the previous but with base fixed-end columns.

The three fundamental free oscillation frequencies for the described cases are reported in table 2.

Case #	Fundamental Frequencies [Hz]		
	Mode 1	Mode 2	Mode 3
1	2.27	3.08	4.27
2	2.44	3.32	4.58
3	4.39	5.95	6.62

Table 2

The first two modes are the same for the three cases considered and are essentially horizontal vibrations along transversal direction: these two modes, for case 3, are reported respectively in figures 4 and 5. For cases 1 and 2 the third mode is again an horizontal vibrating mode while it is a vertical one of the cantilever part of the structure for case 3.
By comparison between cases 1 and 2 it is possible to note that for this structure the brick wall doesn't play an important role on the fundamental frequencies: this is due to the fact that vibrations related to the fundamental frequencies are essentially orthogonal to the plane of the wall, even for case 1.

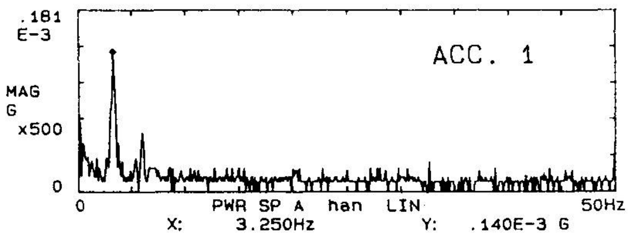
4. IN-SITU DYNAMIC TESTS

The tests on both structures have been performed applying at a pre-established point a sinusoidal force (with known intensity, direction and frequency) by a dynamic exciter, and acquiring the accelerations at significant points of the structures by means of some piezometric accelerometers, which were connected to a recording system and a function analyser allowing on-line check of structural response.
For the mixed structure a 200 Kg counterrotating masses dynamic exciter has been used; the exciter and accelerometers location are showed in figure 1.
For the steel roofing structure, due to the lower total mass, a 50 Kg dynamic exciter has been used; the location of the instruments is showed in figure 2.
The tests were performed arranging the dynamic exciter so as to provide horizontal forces in the top floor of the mixed building and in the plane of the roof for the steel structure.
Accelerations have been recorded in correspondance of the stationary response of the structure for several forcing frequencies and for the free final vibrating transients.
The investigated frequencies range from 1 to 8 Hz for both structures.

5. COMPARISONS

5.1 Results and comparisons for the mixed structure

Figure 3 shows the spectra of the accelerations recorded by accelerometers 1 and 2 (see fig. 1) during the free vibration transients: the values observed for the fundamental frequencies are respectively 3.25 and 6.25 Hz. By comparison with table 1 it can be noticed that the first fundamental frequency is satisfactorily consistent with the numerical one for case no. 3, while the second one is underrated in the same numerical model.
The consistency of the fundamental numerical and physical frequency only for model no. 3 states that the structure behaves like a frame with full continuity at least for moderate applied forces.



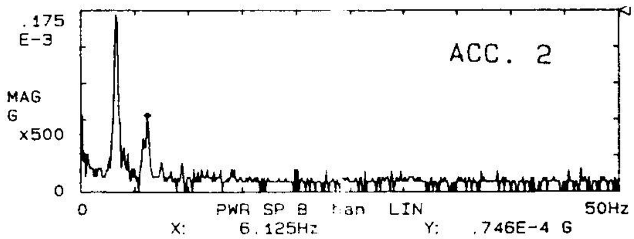


Fig. 3 - Mixed structure: power spectra

5.2 Results and comparison for the steel roofing structure

The main numerical and test results are reported in figures 4÷6. Figures 4 and 5 show the two fundamental theoretical vibrating modes of the structure for case no. 3, related to frequencies of 4.39 and 5.95 Hz, and the accelerations of the more interesting points recorded respectively at 4.5 and 5.5 Hz.

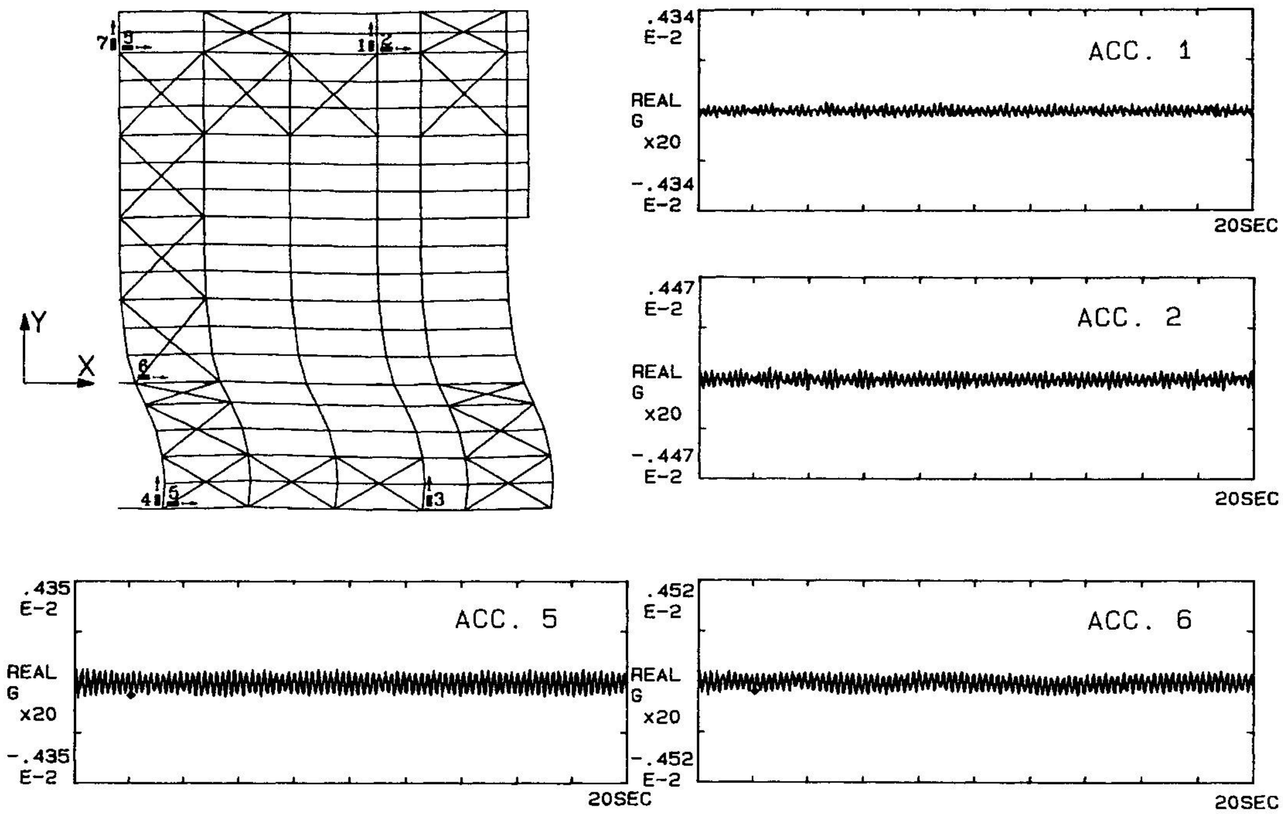


Fig. 4 - Mode 1 of the numerical model (4.39 Hz) and recorded accelerations at 4.5 Hz.

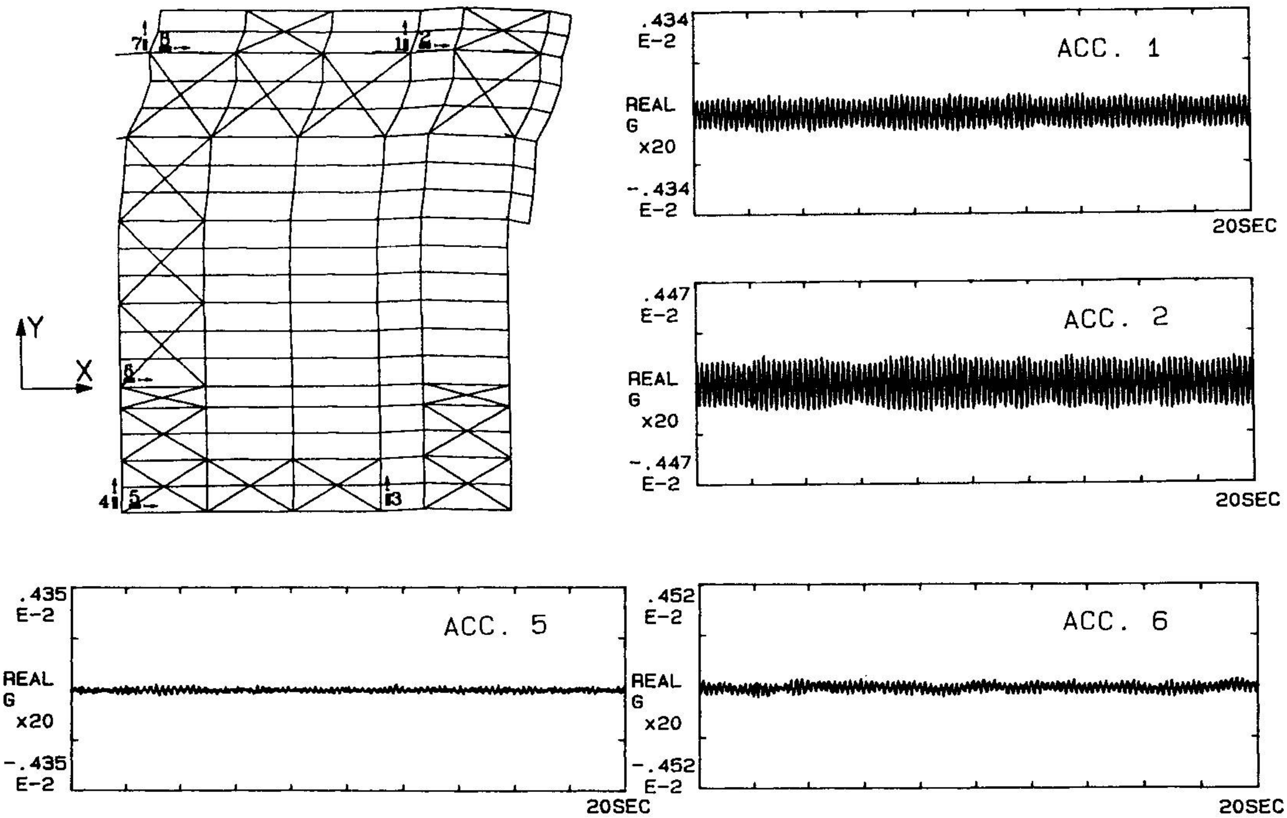


Fig. 5 - Mode 2 of the numerical model (5.95 Hz) and recorded accelerations at 5.5 Hz.

By comparison between the amplitude of the recorded accelerations and of the theoretical vibrating modes, it can be noticed that at 4.5 Hz the structure moves approximatively like the first fundamental numerical mode, while at 5.5 Hz it vibrates like the second one.
Figure 6 shows the response spectra of the free vibrating accelerations recorded by accelerometers 2 and 5 and states that the most energy contents are at 4.45 Hz and 5.45 Hz respectively for accelerometer 5 and 2.
These results are fully consistent with the first two modes of the numerical analyses: indeed, accelerometer 5 doesn't show the second frequency because it hasn't an appreciable vibration in the second mode and accelerometer 2 shows the same behaviour but regarding the first mode.

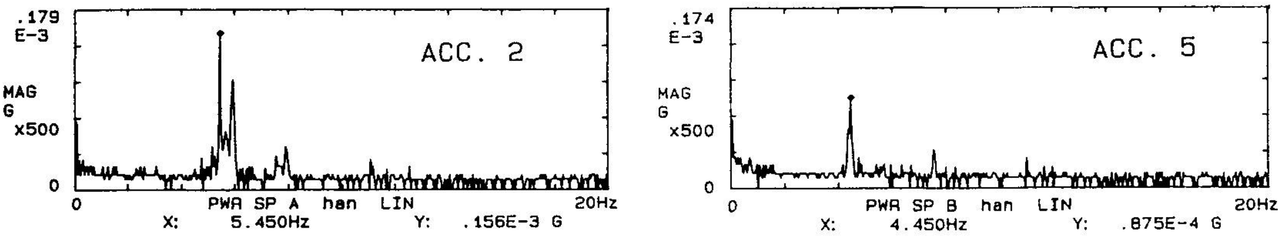


Fig. 6 - Steel roofing structure: power spectra

The described figures of the recorded data show that observed fundamental frequencies are close with those obtained by numerical analysis in the case of base fixed-end columns (case no. 3), and also the actual vibrating modes are consistent with those obtained by the same model.

6. CONCLUSIONS

The capability of evaluating the actual structural behaviour of buildings at service load levels by means of simple in-situ dynamic tests has been investigated.
It has been pointed out that in-situ dynamic tests could supply useful informations about the actual restraint of building connections; these informations, if properly recognized in very simple numerical models, allow the global structural behaviour for "service load levels" to be evaluated. It is important to stress that these models must be able to decribe the full set of nodal displacements and correctly evaluate the mass distribution on the structure: therefore, generally, 3-D numerical models are necessary.
Finally, the correct interpretation of the results of in-situ dynamic tests is directly related to the energy supplied to the structure; due to this fact only in the case of buildings with very simple mesh and with low total masses the hand-held hammer method can be usefully used [4].

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