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Strength Reduction in Masonry Due to Dynamic Loads

Réduction de la résistance de la maçonnerie sous charges dynamiques

Festigkeitsrückgang im Mauerwerk unter dynamischer Last

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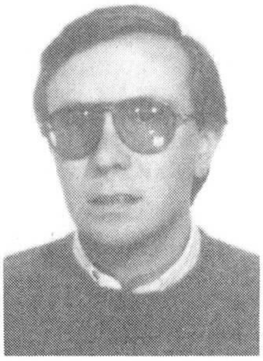

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SUMMARY

The results of a broad experimental investigation of the behaviour of scaled models of well arranged masonry panels, made of yellow tuff stone and cement mortar, are shown. Force-displacement diagrams have been plotted both in the case of dynamically prestressed and non- prestressed specimens. Significant strength reductions have been observed in cases with a high number of cycles.

RÉSUMÉ

L'article présente les résultats d'un grand nombre d'essais sur des panneaux de maçonnerie de tuf jaune et de mortier. Des diagrammes forces-déplacement ont été réalisés dans les deux cas de maçonnerie précontraintes ou non. Une réduction notable de la résistance a été constatée dans le cas de la maçonnerie soumise à un grand nombre de cycles de charge.

ZUSAMMENFASSUNG

Gezeigt werden die Ergebnisse einer experimentellen Studie über das Verhalten eines gut gebautem Mauerwerks, bestehend aus gelbem Tuff, Mörtel, und Zement . Die Diagramme Stärke-Bewegung von dynamisch belasteten und unbelasteten Modellen werden gezeichnet. In dem Fall von einer grossen Zahl von Zyklen wurde eine empfindliche Festigkeitsreduktion des Mauerwerkes gefunden.

1. INTRODUCTION

Masonry constructions behave very well under vertical loads but they are not suitable to bear horizontal forces, especially those due to seismic actions. Strong vibrations may cause the collapse of the structure but also dynamic stresses due to microvibrations play an important role in the lifespan of 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. In this condition the lifespan of structures cannot be long.
This is certainly true for the masonry building of the Naples area, characterized by the traditional weaving, called "a sacco". It is made by two sheets of bricks with a rubble fill between them. This kind of masonry is not suitable for buildings in seismic area.
In this paper a well arranged masonry is proposed and its behaviour is investigated. In a well arranged masonry wall the two sheets are connected by cross stones, without rubble fill.
The aims of the research project are to investigate the load-carrying capacity both under vertical and horizontal loads and to analize changes in the mechanical behaviour of such masonry walls due to dynamic loads. A wide numerical investigation has been performed on 1:6 scaled models of masonry panels. A set of panels has been first subjected to dynamic loads, considering different values of amplitude, frequency and number of cycles.
The panels have been subjected to a fixed vertical load N and a variable horizontal force T at the same time and the corresponding T-Δ diagram (Δ= horizontal displacement) has been plotted.
The experimental results have also been compared with those obtained using 3-D finite element models [3].

2. SPECIMENS AND INSTRUMENTS

As we have already said the tested specimens represent masonry panels on the scale of one to six. The panels are made of little stones of yellow tuff, which characterizes the old buildings of the Naples area. The stones, whose size is 7.0*5.0*2.5 cm³, are extracted by cutting from the original practical used stones; a cement mortar, with a water/cement ratio equal to 0.5, has also been used. Two kinds of specimens, respectively with the ratio B/H=1 (squat panels) and B/H=0.67 (slender panels), have been considered in order to study the behaviour of characteristic masonry walls. Fig. 1 shows the two models and their size.

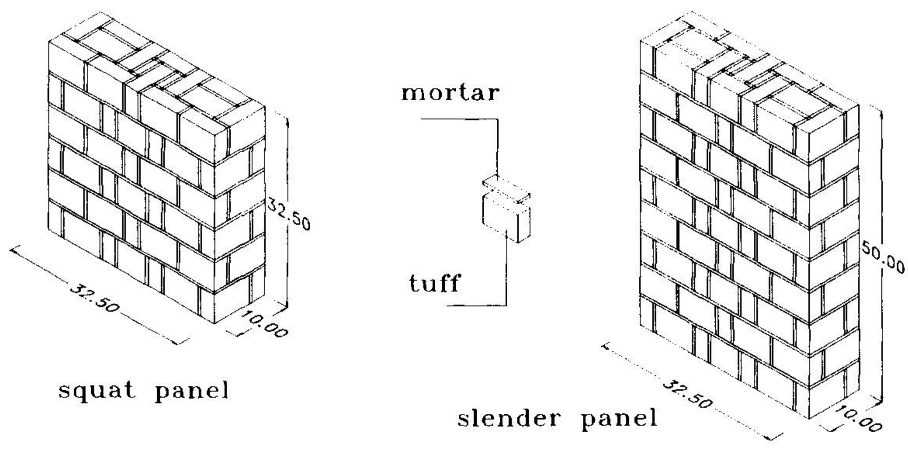

Fig. 1 Specimens

Two kinds of equipment have been used for the experimental tests, the first one consisting of a traditional machine for the simple compression tests, and the measurement of the corresponding

strain. A second equipment has been used to test the panels subject to a fixed axial force and to an horizontal force increasing from zero to the collapse value. This was composed by the following parts:
- three vertical jacks of 30.0 kN with manometers, linked in parallel to an independent oil-dynamic station;
- one hydraulic jack, controlled by an oil-dynamic station, which allows the execution of static and dynamic tests, in which the force law is harmonic with given amplitude and frequency;
- an opposition structure for the jacks, joined to the fixed structures of the laboratory;
- a rigid table on which the models could be constrained;
- a computer which allowed the storing and the drawing in real time of the experimental results.

3. SIMPLE COMPRESSION TESTS

Preliminary compression tests on the basic materials have been carried out. Twelve specimens of tuff and ten specimens of mortar have been tested.
The following values of the characteristic strength have been assumed:

$$f_{bk} = 1.7 \quad MPa$$
$$f_{mk} = 13.7 \quad MPa$$

respectively for the tuff and the mortar, obtained from the average values using the formula:

$$f_k = f_m - k\,s$$

where s is the mean square error and k=1.64.
Eight slender panels and six squat panels have been subjected to compression test. The results are summarized in Tabs. 1 and 2.

No.	Size (cm)	Weight (Kg)	Collapse load (kN)	Compr. strength (MPa)
1	33.0*9.60*50.0	20.90	160.00	5.05
2	32.5*10.0*50.0	20.20	156.00	4.80
3	32.0*10.1*49.5	20.20	162.00	4.98
4	33.0*10.0*50.0	20.95	170.00	5.15
5	33.0*9.80*49.5	20.00	158.00	4.89
6	32.5*9.70*50.0	20.20	160.00	5.07
7	33.0*10.0*49.5	20.50	156.00	4.73
8	33.0*9.60*50.0	20.50	159.00	5.02

Tab. 1 Results of the tests on the slender specimens

No.	Size (cm)	Weight (Kg)	Collapse load (kN)	Compr. strength (MPa)
1	32.5*10.0*32.5	13.00	147.00	4.52
2	33.0*10.0*32.5	13.10	150.00	4.54
3	32.5*10.0*33.0	13.10	156.00	4.80
4	33.0*9.60*33.0	12.90	154.00	4.86
5	33.0*9.80*33.0	13.20	152.00	4.70
6	32.5*9.80*32.5	12.90	160.00	5.02

Tab. 2 Results of the tests on the squat specimens

From these we can deduce the average collapse stress σ_m, the characteristic strength f_k, the yield axial force N_u and the allowable stress σ_{adm} for both slender and squat panels, reported in Tab. 3.
The experimental values can be compared with those given by the expressions of the Italian Code

[6] and those suggested by other Authors, which relates the masonry strength with the brick and mortar strengths.

	B/H=0.67	*B/H*=1
σ_m (MPa)	4.96	4.74
f_k (MPa)	4.64	4.29
N_u (kN)	150.93	139.49
σ_{adm} (MPa)	0.93	0.86

Tab. 3 Collapse, characteristic and allowable stresses

We can notice that the strength of the panels is much higher than we would expect. The reason of this behaviour is certainly due to the particular masonry weaving, that we have already called well organized weaving. A well organized masonry panel is quite similar to an homogeneous body in comparison with the traditional masonry, called "a sacco". The loading capacity of a masonry structure depends not only on the strength of the used materials, but also on the weaving.
It is interesting to observe that the panel with the ideal homogenized cross-section would have a collapse axial force:

$$N_u = 161.00\ kN$$

which is coincident with the experimental value.

4. THE BEHAVIOUR UNDER HORIZONTAL LOADS

As we have already said the aim of the project was to investigate the effects of horizontal vibrations on the masonry behaviour subjected to horizontal forces.
Two groups of tests have been carried out: the first one have been carried out on panels that have never been loaded before, the second one on models which have first been subjected to a dynamic load. The collapse tests have been carried out by loading the panels, subject to a fixed vertical load, with a variable horizontal force. Four values of the vertical load have been considered: 30, 45, 52.2 and 60 kN, representing the effects of dead loads and variable vertical loads.
The horizontal load has been increased step by step, from zero to the collapse value, and the corresponding horizontal displacements have been collected. The typical *T-Δ* diagram have been plotted. During the tests the appearance of the damages (cracks) and the collapse mechanisms have been pointed out.
The vibration effects has been simulated by loading the panels, which were subjected to a uniform vertical load, to an horizontal beating force. Forces variable in the interval [0,5] kN have been applied, with the frequency of 4.2 Hz. Different values of cycles number have been considered: 5000, 10000 and 15000. Forces of lower amplitude or with a lower number of cycles have negligible effects on the load-carrying capacity of the panels. The considered frequency, the maximum value for the used machine, simulated quite well the effects due to ambient vibrations [5].
Seventy models have been tested: thirty with *B/H*=0.67 and forty with *B/H*=1.
The two kinds of panels showed different mechanisms of collapse, as we expected. The higher panels reached the collapse by yielding due to the compression at the base corner which is at the opposite side with respect to the horizontal force. The smaller panels showed on the point of collapse the classical diagonal crack due to the shear stress. These behaviours agrees with the theoretical considerations reported in [1] and [2]. According to these considerations we can classify the masonry panels as slender or as squat.
The experimental results are summarized in the following. The diagrams *T-Δ* (horizontal force against horizontal displacement) are drawn for both dynamically prestressed and not prestressed panels.

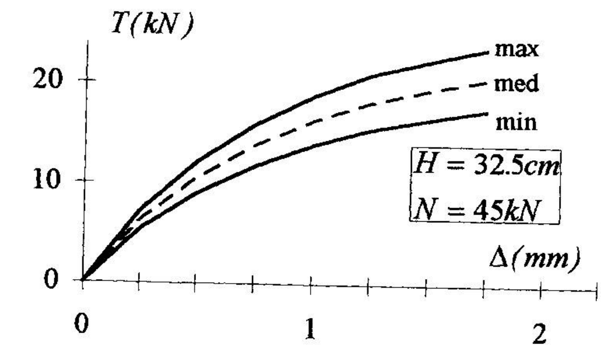

Fig. 2a

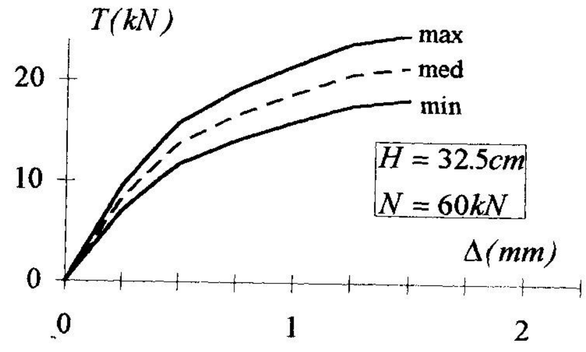

Fig. 2b

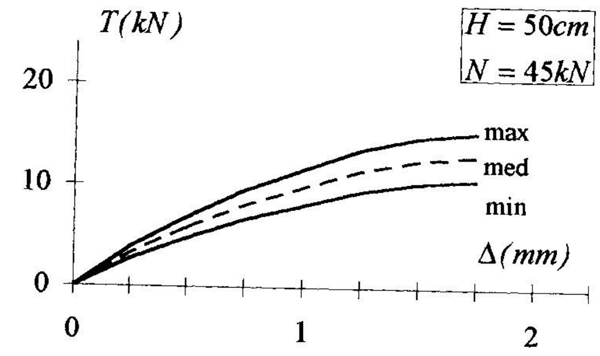

Fig. 3a

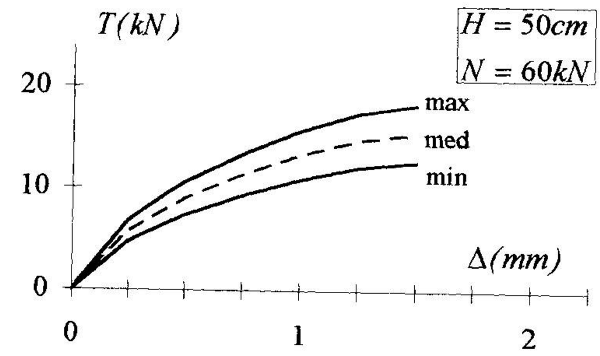

Fig. 3b

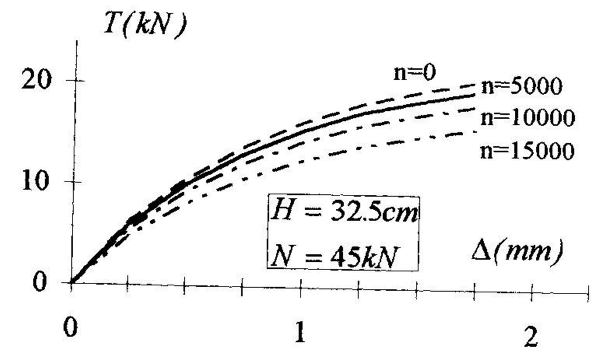

Fig. 4a

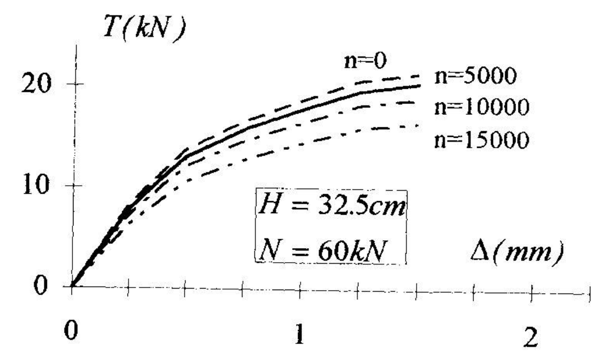

Fig. 4b

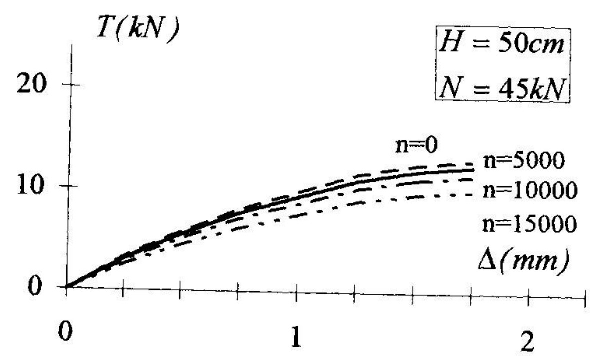

Fig. 5a

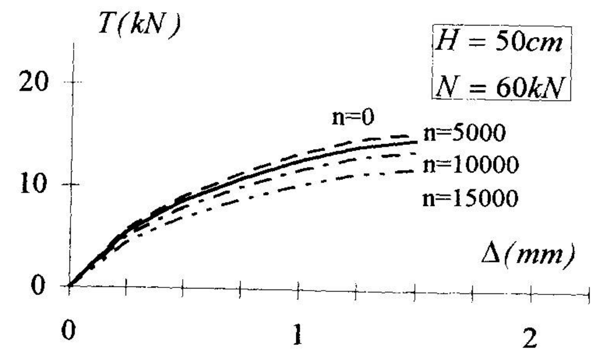

Fig. 5b

Fig. 2 shows the curves relative to the squat models, for two values of N; the similar curves for the slender panels are reported in Fig. 3. The two solid lines define the zone of the plane T-Δ, which contains the experimental curves. The dashed one represents the average curve.
The experimental results appear quite scattered. This cannot be considered an anomaly, but an expected result associated with the real behaviour. In fact, because the masonry is a craftsmanship product, both in the real building and in the models, the strength of the panels cannot be defined by only one curve as we can do for industrial products, but by a region in which we can probably find the structural behaviour.
Figs. 4 and 5 show the average curves relative to the dynamically prestressed specimens; n is the number of cycles. The dynamically prestressed panels behaviour is quite similar to that of the non-prestressed models, as we can see from the analysis of the diagrams. The experimental research has also shown that masonry, characterized by a well arranged weaving and cement mortar, suffer very low reduction of its load-carrying capacity when it is subjected to dynamic loads, especially when the number of cycles n was not greater than 5000. If n>5000 the masonry fabric feels the effects of the dynamic stresses, although the weaving was well arranged, and the curves T-Δ are softer.
The reduction of the collapse load is very low in the case of 5000 cycles, more evident for n>5000 as we can see from the diagrams.

5. CONCLUSIONS

A well arranged weaving of the masonry determines an increasing of the strength under vertical loads, and a noticeable reduction of the vulnerability with regards to horizontal vibration effects. Therefore a well arranged weaving is more suitable than a traditional one to guarantee a longer life to masonry structures. For this reason well arranged masonry buildings may characterize a new builidng age, both in seismic and aseismic areas.

ACKNOWLEDGEMENTS

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