



APPLICATION OF RESISTANT OVERLAYS IN PREVENTION OF PROGRESSIVE COLLAPSE IN MASONRY BUILDINGS

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Abstract

The purpose of this work is to investigate one type of progressive collapse mechanism and the effect of reinforced and unreinforced mortar overlays on the strength of masonry walls. In case of a localized damage in the structure of a building, alternative resistance mechanisms can be mobilized to prevent the progressive collapse. To activate these mechanisms, reinforced elements are required, such as ties, slabs, beams, columns or grouted blocks. The reinforcement of these elements must be well anchored and interconnected with the rest of the structure to allow them to act as ties in strut-tie models. Some tests were made to observe the efficiency of ferrocement or reinforced mortar overlays in the restoration of damaged masonry walls. The results are compared with other tests using unreinforced mortar overlays, steel bar ties and external prestressing tendons.

Key Words

ferrocement, reinforced mortar, strengthening, progressive collapse.

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1 Introduction

The progressive collapse, also called "damage in chain", can be defined as a type of gradual damage in which the damages in the structure are not proportional to the initial cause. The occurrence of the progressive collapse is associated with the exceptional actions that are not, in general, considered in the project of the structures. The exceptional actions are usually not part of the group of actions considered for the project of a building, as actions due to explosions and impacts. It is also important to consider the accidental actions that can cause a process of progressive collapse, as the action of earthquakes, fire and etc.

These confirmations have gained importance after an accident in England, 1968 where a 23-floor building, The Ronan Point, built with precast concrete structure, suffered a progressive collapse after the explosion of a combustible gas cylinder on the 18^o floor. Due to the removal of one of its structural walls, the slabs above the damaged level collapsed, taking to damage an entire sector of the building.

There are, basically, two ways to take precautions against the progressive collapse:

- Avoiding the possibility of occurrence of the accidental damage;
- Admitting the possibility of occurrence of the accident and avoiding the progressive collapse.

Evidently the first option is not always feasible to be carried out. It is clear that in some cases preventive measures can minimize the probability of the occurrence of accidents. For example, the construction of obstacles to prevent against the eventual impact of vehicles against the walls of the first floor. However, the complete elimination of those possibilities would be uneconomical.

In the second option the damage of a significant part of the structure is avoided in case of accidents and local flaws. In those cases the planners should be aware of the identification of the points where the occurrence of an accident would be more probable and to provide the structure with alternatives to direct the loads.

In practice, for example in some cases of cellular masonry buildings, this means that after a wall or a part of a wall is removed, the addition of stress on the slabs and the other walls are checked to make sure that the remaining structure can resist this. It is important to emphasize two points in this matter: elements should be removed one by one and the security coefficients can be reduced or eliminated. Figure 01 illustrates stress redistribution due to the located damage.

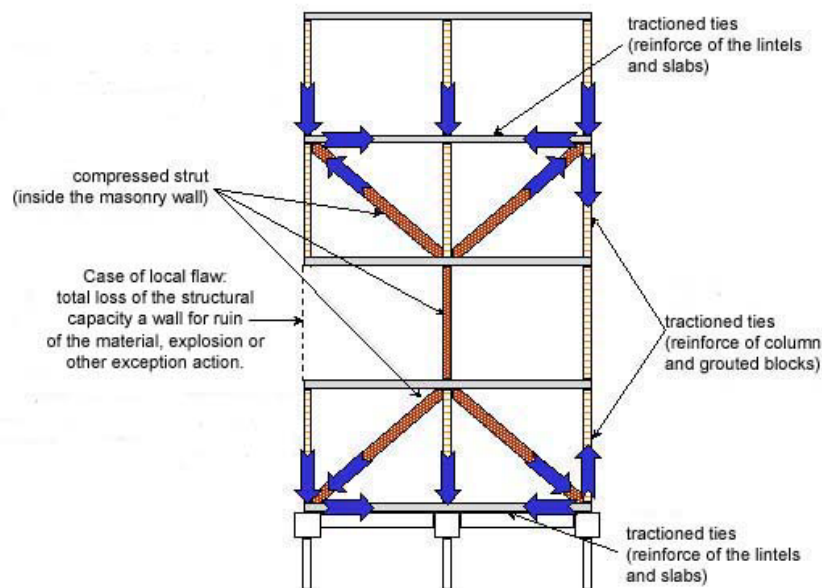


Figure 1 Illustration of possible resistant mechanism against the progressive collapse.

In Brazil some cases of damage were registered in the northeast of the country, in masonry buildings with 4 floors. The most serious cases happened in the city of Olinda, in November of 1999, where four people died in the collapse of the first building (Figure 2) and other seven in the collapse of the second building (Figures 3). The inspections pointed out damages in the foundation and that non structural ceramic units were used. That constructive system developed in an empiric way contains procedures which are incompatible with the good practice of Engineering, since the materials and consolidated techniques along with minimum procedures of quality control were rejected.



Figure 2 Damage of the building 1.



Figures 3 Collapse of the building 2.

The Brazilian masonry codes are omitted in relation to the progressive collapse. However the British code BS 5628 presents a series of prescriptions, some general, for buildings up to 4 floors and other more specific ones for constructions of 5 or more floors, in article 37 (Design: accidental damage).

This paper presents results of an experimental analysis of ceramic block walls that were reinforced against the progressive collapse by diverse ways. One of the main alternatives was the application of the ferrocement. Others considered alternatives were: simple mortar, reinforce with steel bars and prestressed tendon.

2 EXPERIMENTAL PROGRAM

The experimental program consisted of testing masonry models for the study of prevention mechanisms against progressive collapse. The decision of testing models with this physical format was taken with the purpose to create situations that simulate the collapse mechanisms in a structure, causing compression stress, traction and shear. In these situations the effectiveness of the coating, the rehabilitation techniques in the prevention against progressive collapse and the improvement of the wall working under conditions close to the real cases were observed. The walls were tested in three different situations: no damage, rehabilitated and reinforced walls.

2.1 Geometric Characteristic of the models

The series idealized for the tests were two models with two conjugated panels (denominated North and South) of non structural ceramic blocks. The dimensions of the panels were 120 x 120 centimeters and webs of 10 x 50 x 120 centimeters in their extremities. Each model was built on a slab of reinforced concrete with dimensions of 270 x 50 x 10 cm. That slab was simply supported on a concrete block (20 x 50 x 20 cm) in the middle. The lintel with a height of 10 cm outlined the top of the whole model (FIGURE 4).

2.2 Construction procedures and properties of the materials

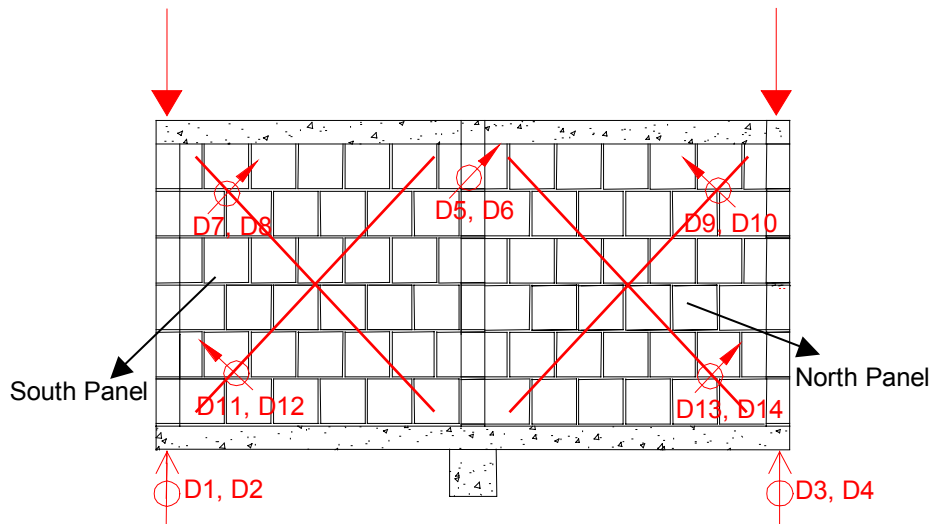
The walls were made of non structural ceramic units of masonry with 6 hollows, parallel to the face of the bottom of the unit. The nominal dimensions of the units were 20 x 20 x 9 cm and they presented resistance to compression of 6, 0 MPa. The embedding mortar was prepared with a volume proportion of 1:0,5:6 (cement:lime:sand) and presented resistance of 7 MPa. The coating mortar was applied manually with a thickness of 2 cm, volume proportion of 1:0,5:6 (cement:lime:sand) and presented a resistance after 28 days of 9 MPa.

The concrete applied in the slab presented resistance of 20 MPa dosed with the proportion of 1:2,76:3,23 (cement:sand:agregate). The solid block of concrete served as a support for the slab which was made of the same concrete.

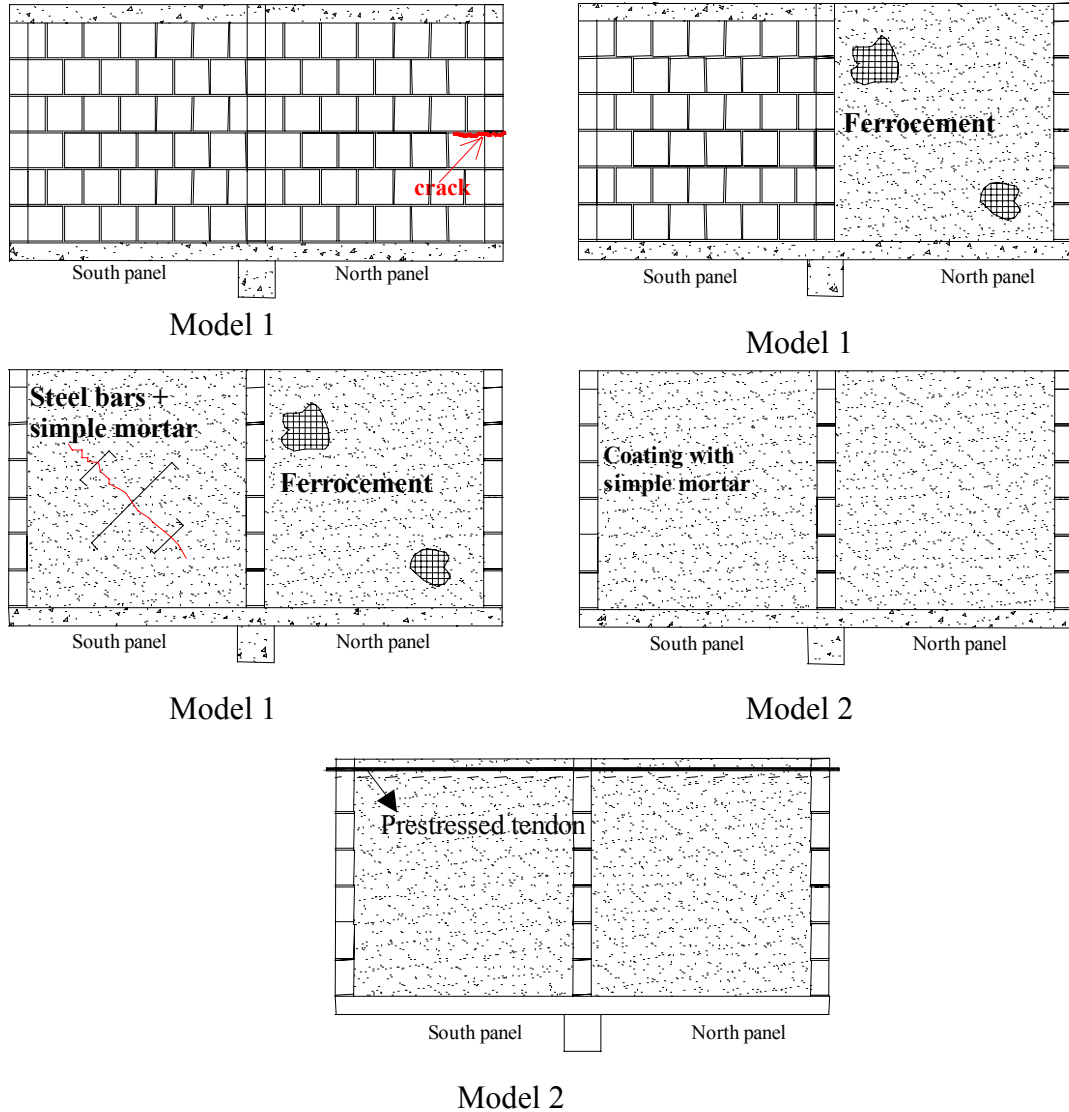
The lintel was built in concrete with the proportion of 1:3:2 (cement:agregate:sand) and reinforced with 2 bars of $\phi = 8$ mm. After the building the models were painted with lime for a good visualization of the cracks during the tests.

2.3 Tests of the models

The models were tested according to the model of Figure 4. The model supported on the concrete block in the middle and concentrated loads were applied on the extremities. For the application of these loads servo-hydraulic testing machines were used with a capacity of 500 kN to enable the realization of the tests with controlled deformation. The load speed was 0,005 mm/sec and the displacements were measured as seen in Figure 4. Figure 5 illustrates the sequences of the tests for each one of the built models.



Figures 4 Instrumentation used in the models.



Figures 5 Coating situations of the models.

2.3.1 Model 1

a) Panels without coating

During the transport of the specimen the north panel was damaged, affecting the test partially. This caused a premature crack in the north panel under a load of 19 kN. The pre-existent crack had been prolonged with the increase of the load and a new crack in "stairway" format appeared in the diagonal of the wall. The south panel didn't suffer any damage during the test.

b) North panel reinforced with ferrocemento and south panel without coating

The north panel was reinforced with ferrocement (reinforced mortar with welded meshes of 2,77 mm wires, spaced 50 mm) passing over the lintel at a height of approximately 5 cm and tested again. As the south panel didn't have any reinforcement the damage happened obviously at this side, under a load of 35 kN. Vertical cracks appeared in the lintel and in the main diagonal of the wall also in "stairway" format. The north panel didn't suffer any damage during this test, since no fissure was detected.

c) North panel reinforced with ferrocemento and south panel reinforced with steel bars and simple coating

The south panel was reinforced with steel bars of $\phi = 5\text{mm}$ (perpendicular to the diagonal cracks) and coating of simple mortar with the proportion of 1:0,5:6 (cement: lime: sand) and thickness of 2 cm. It presented a resistance to compression of 9 MPa. The coating was applied on the whole model (also in the lintel). The rupture of the model was given by damage of the south panel. The cracks that appeared in the model deviated from the region where the steel bars were and spread towards the central web. The model reached a maximum load of 70 kN. Many cracks were not observed in the north panel.

2.3.2 Model 2

a) Panels with coating

The model 2 was built entirely with simple mortar with the proportion of 1:0,5:6 (cement: lime: sand) and thickness of 2 cm. The model reached the maximum load of 71 kN. The first cracks happened with a load of 53 kN. They were diagonal towards the central web of the model. It is important to emphasize that the cracks that appeared in the masonry panels weren't in great amount and neither of large openings. The test was interrupted when the crip of the lintel bars was observed. It was decided then, to reinforce the model and test it again.

b) Paneles with coating and reinforcement with prestressed tendon

In the test of the model it was observed that the lintel reached the resistant capacity when the reinforce reached its limits of crip. So, The decision was made to reinforce it with two prestressed tendons with force of approximately 20 kN. The model reached the maximum load of 150 kN. The final configuration of damage was a diagonal crack in one of the masonry panels. Although the other masonry panel did not fail equally, the configurations of the cracks were similar.

- Photographic documentation of the tested models damage.



Figures 7 Damage of the model without coating.



Figures 6 Damage of the model with steel bars.



Figures 8 Damage of the model with prestressed tendons.

3 ANALYSIS OF THE RESULTS

Table 1 and diagram of the Figure 6 (*load x displacement*) show the values obtained in the tests of the models carried out for analysis of the prevention mechanisms for the collapse.

All the tests of masonry walls carried out in this investigation were made with the controlled deformation to obtain the curve tension x deformation of the structure until to the moment of the damage and after the resistance peak. So, it was not only possible to evaluate the resistance increment and rigidity provided by the application of the coatings, but also to verify their influence in the ductility of the structural element.

The panels without coating demonstrated structural behavior as expected, presenting close to the damage diagonal cracks in stairway form. This fissure configuration was the same as observed in the shear tests in masonry walls carried out in the Laboratory of Structures.

The application of the different types of mortar and sand coating in the walls provided resistance and rigidity in the tested models. The application of the simple mortar coating doubled the resistance of the non coating walls.

Table 1 – Results of the tests (progressive collapse).

Models	Panels		$F_{exp.}$	
	North	South	North	South
Model 1	Without coating (damage)	—	19	—
	—	Without coating(no damage)	—	35
	ferrocement (simple mortar + steel meshes)	Steel bars + simple mortar	85*	70
Model 2	With coating (simple mortar)	With coating (simple mortar)	71	71
	Prestressed tendon	Prestressed tendon	150	150

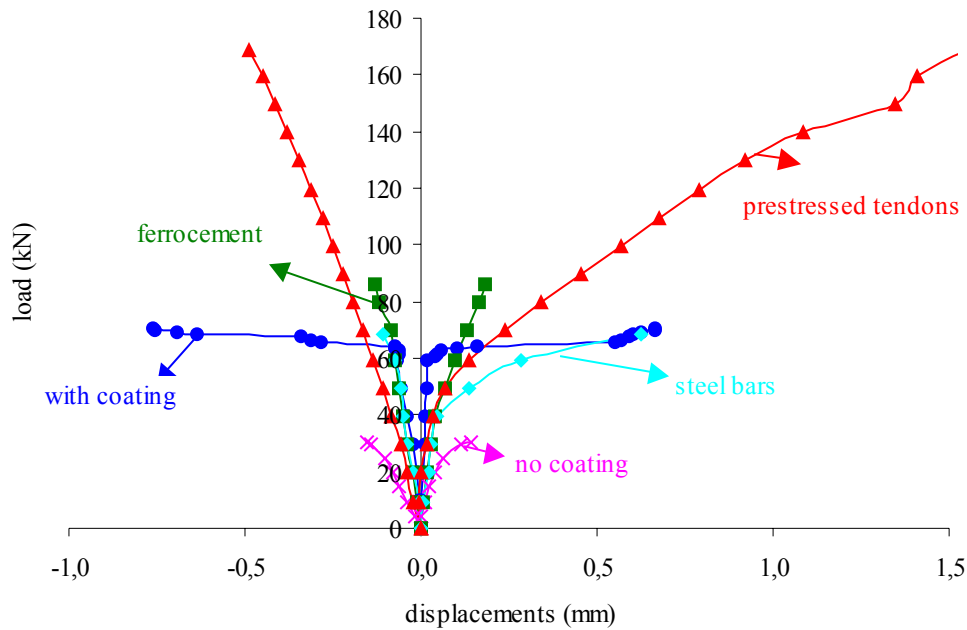
Observations:

$F_{mort.as.} = 7 \text{ MPa}$

$F_{coating \text{ mortar}} = 9 \text{ Mpa}$

* = no damage of the model

$F_{exp} = \text{maxim experimental load}$



Figures 6 Load vs. displacement diagram.

In the walls reinforced with steel bars the final load was also twice as high as the walls without coating. The damaged wall acquired its initial resistance and reached the same resistance as that of an entire coated wall.

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It was not possible to obtain the last load of the panel reinforced with ferrocement. But by observing Figure 6 the load x displacements curve, even in the linear phase, an improvement in the rigidity and ductility of the panel can be seen. It can be concluded that the meshes collaborated in controlling the appearance of cracks in the wall and retarded the fracture mechanisms. The wall reinforced with prestressed tendon presented better ductility and final load than the other test models. But it cannot be concluded that it is the best because a more complete analysis of these cases must be developed.

The results obtained so far indicate that the technique of resistant coating application is efficient. But its analysis is still being developed along with theoretical experimentations with the employment of the Finite Elements Method.

4 CONCLUSIONS

The masonry walls or parts of them under shear stress can have the resistant capacity significantly increased by the resistant coating. This potential of improvement makes the technique of resistant coating application mainly attractive in the case of horizontal actions and the dynamic actions as earthquakes.

The results of this investigation demonstrate that the coating of the walls, in general, increase their resistant capacity and rigidity and under certain conditions even their ductility. Consequently, it can be said that the technique in the analysis has conditions

of being applied in the rehabilitation of walls and other masonry elements as well as in the project and execution of elements with special properties of performance.

The information collected and analyzed already constitutes an important reference in the re-evaluation of the safety structure of a fully constructed building. Based on the information, it is possible, for example, to evaluate the safety of a building that is under suspicion and has coating elements. In this case, the coating is able to carry out an important part in the stability of the construction.

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