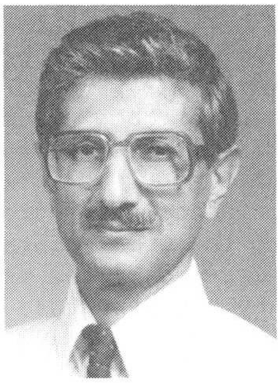
Reinforced Concrete Sheath for Repair of Damaged Masonry Walls

Enveloppes en béton armé pour renforcer les murs en maçonnerie endommagés

Stahlbetonmembranen zur Reparatur beschädigter Mauerwerkswände

Bezaleel BENJAMIN
Professor
University of Kansas
Lawrence, KS, USA



Bezaleel Benjamin, born in 1938, received his B.E.(Civil) from Bombay Univ. and has both M.Sc(Eng) and Ph.D. degrees from the University of London. He is now Professor of Architecture and Architectural Engineering at the University of Kansas, where he has taught for the past 24 years.

SUMMARY

This paper describes theoretical and experimental work on the use of a thin, reinforced concrete sheath for the repair of load-bearing masonry walls damaged by earthquakes. The thin sheath is prevented from buckling by the cracked masonry wall to which it is tied. The experimental work on model walls investigates the reserve strength, in buckling, of severely cracked masonry walls under vertical loading. It then determines the improvement in load-carrying capacity by the provision of the thin sheath tied to the old wall. The sheath can then be faced to return the building, visually, to its original architectural appearance.

RÉSUMÉ

Cet article décrit les travaux théoriques et expérimentaux destinés à la consolidation de murs porteurs en maçonnerie endommagés par les effets sismiques. Ce renforcement prévoit d'enrober les structures défaillantes par des voiles minces en béton armé, ancrés dans la maçonnerie fissurée de façon à en empêcher le flambement local. A partir d'études expérimentales sur modèles de parois, l'auteur examine la capacité portante résiduelle sous charge verticale des murs fortement fissurés, puis détermine la résistance complémentaire que doivent assurer les enveloppes de consolidation. Il indique en outre la possibilité de revêtir les voiles d'enrobage pour redonner aux bâtiments leur aspect architectural initial.

ZUSAMMENFASSUNG

Der Beitrag beschreibt theoretische und experimentelle Arbeiten zur Reparatur erdbebengeschädigter tragender Mauerwerkswände mittels dünner Stahlbetonumhüllung. Die dünnen Membranen werden durch Ankerung an das gerissene Mauerwerk am Ausbeulen gehindert. Die experimentelle Arbeit untersucht die Resttragfähigkeit der stark gerissenen Mauerwerkswände gegenüber Instabilität unter Vertikallast. Anschliessend wird die Erhöhung der Tragfähigkeit infolge der hinzugefügten Membranen bestimmt. Die Membran kann zusätzlich verkleidet werden, um dem Gebäude optisch sein ursprüngliches architektonisches Aussehen zurückzugeben.

1. INTRODUCTION

Load-bearing masonry walls damaged by earthquakes develop cracks that make the structure unusable. Existing Codes of Practice consider such walls to be unsafe, resulting in either the building being condemned or expensive renovation that often destroys the architecture of the building. Furthermore, in the case of historic buildings, damaged by earthquakes, both of the existing approaches would be unacceptable.

In all such cases, the assumption is made that cracked masonry walls do not have any reserve strength in buckling, to carry vertical loads, inspite of the fact that the building is still standing. A study of crack patterns shows that under horizontal loads, imposed by an earthquake, masonry walls develop shear failure with diagonal cracking. A photograph of the Oakland Hotel by Langenbach [1] shows this type of diagonal cracking in the external facade of the building. The cracks extend between spandrels at floor levels in the vertical direction and between window openings in the horizontal direction. The removal of internal partitions of that building, prior to the Loma Prieta earthquake of October 17, 1989, led to all the shear loads being carried by the external facade and may have contributed to the damage sustained by the structure [1].

2. THE REINFORCED CONCRETE SHEATH

2.1 The Author's Method

The author's method [2],[3] for the repair and strengthening of such buildings is to provide a thin, reinforced concrete sheath that is tied to the old, masonry wall structure. The thin sheath is prevented from buckling by the masonry wall behind it. The sheath passes around door and window openings and is strengthened by the provision of bands. The sheath was first proposed for load-bearing masonry structures in poor countries where changes in municipal regulations permitted vertical extension of old buildings by the addition of more stories than allowed for in the original design. It is shown in Fig. 1. While this paper considers the reinforced concrete sheath tied to cracked masonry walls damaged by earthquakes, the theoretical analysis given here is still valid because it assumes that the sheath takes all of the vertical loads in the hybrid construction, provided it is prevented from buckling by the masonry wall behind it to which it is tied. Whether this assumption is valid or not has been determined experimentally in Chapters 3 and 4 of this paper.

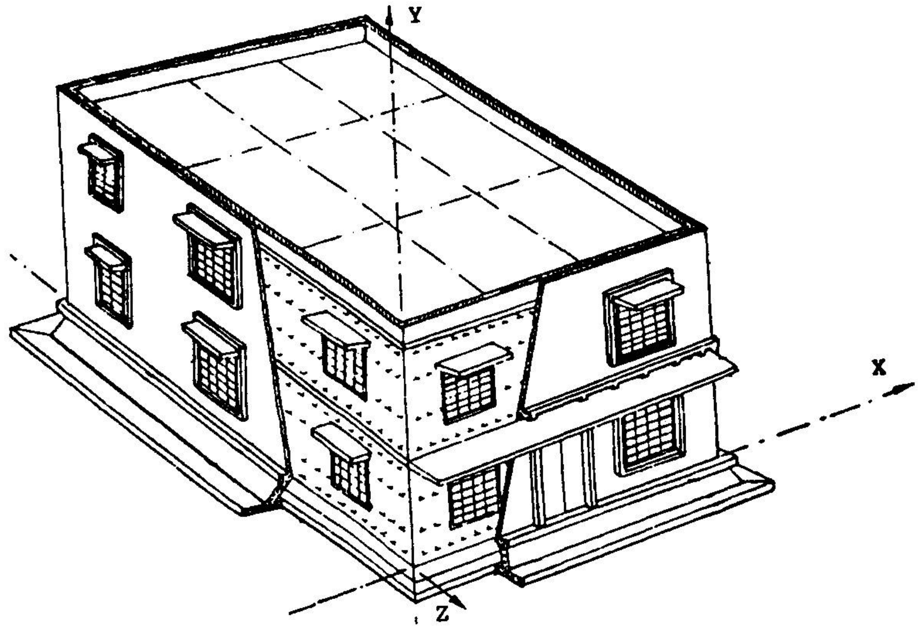


Fig. 1 The reinforced concrete sheath

2.2 Theoretical Analysis of the Sheath

A theoretical analysis of the sheath [3] was carried out using the IMAGES-3D program under a vertical loading of 105 N/mm for seventeen different cases involving variations in thickness of the sheath, size of bands around openings and base conditions. However, as the results showed, only cases A3, B3, D3, E3, F3, G3, with a 76 mm thickness of sheath, and O2 and P2, with a 51 mm thickness of sheath were acceptable, and these are shown in Table 1.

Case	Thickness	Openings	Band Size (mm)	Base	Notes
A3	76 mm	No	---------	Pinned	All plates in
B3	76 mm	No	---------	Fixed	All plates in
D3	76 mm	Yes	152 x 305	Fixed	Lintels and verticals
E3	76 mm	Yes	152 x 305	Pinned	Lintels and verticals
F3	76 mm	Yes	152 x 305	Pinned	All bands in
G3	76 mm	Yes	152 x 305	Fixed	All bands in
O2	51 mm	Yes	152 x 305	Pinned	All bands in
P2	51 mm	Yes	152 x 305	Fixed	All bands in

Table 1 Cases suitable for design and analysed by IMAGES-3D

The dimensions of the wall facades are shown in Fig. 2, with the lines relevant to the rest of the theoretical analysis. The absolute maximum stress in the wall plates and the deflection at Pt. 52, shown in Fig. 2, are given in Table 2 as follows.

Case	Stress (N/sq mm)	Defl. mm
A3	2.854	1.18
B3	2.868	1.04
D3	3.013	0.86
E3	2.985	0.94
F3	2.758	0.97
G3	2.765	0.89
O2	4.357	0.99
P2	4.351	0.91

Table 2 Maximum stress in plates and deflection at Point 52

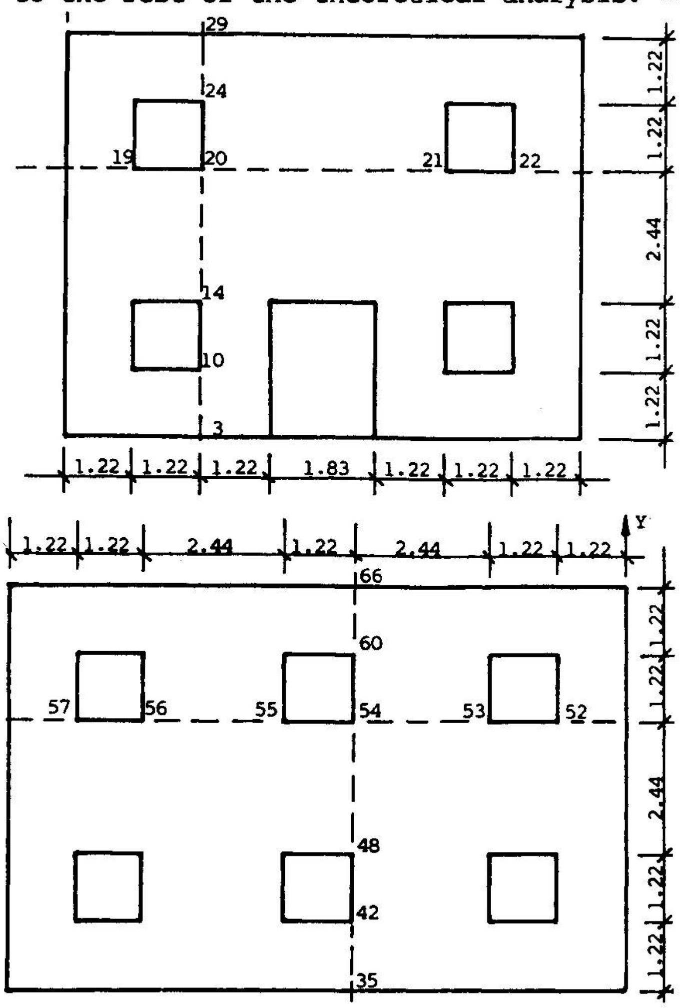


Fig. 2 Wall facades of the sheath

The horizontal deflections of the sheath for all of the cases analysed are shown along lines 19-22 and 52-57 in Fig. 3. A study of these deflections shows that the deflections of the unpunctured sheath (A3, B3) are small. Deleting the plates for door and window openings increased the deflections considerably. The insertion of sizeable bands, 152 mm x 305 mm around openings, however, returned the sheath to a virtually unpunctured condition (D3, E3, F3, G3, O2, P2). Maximum deflections do not occur at the centre of the walls because of wrinkling in the plates.

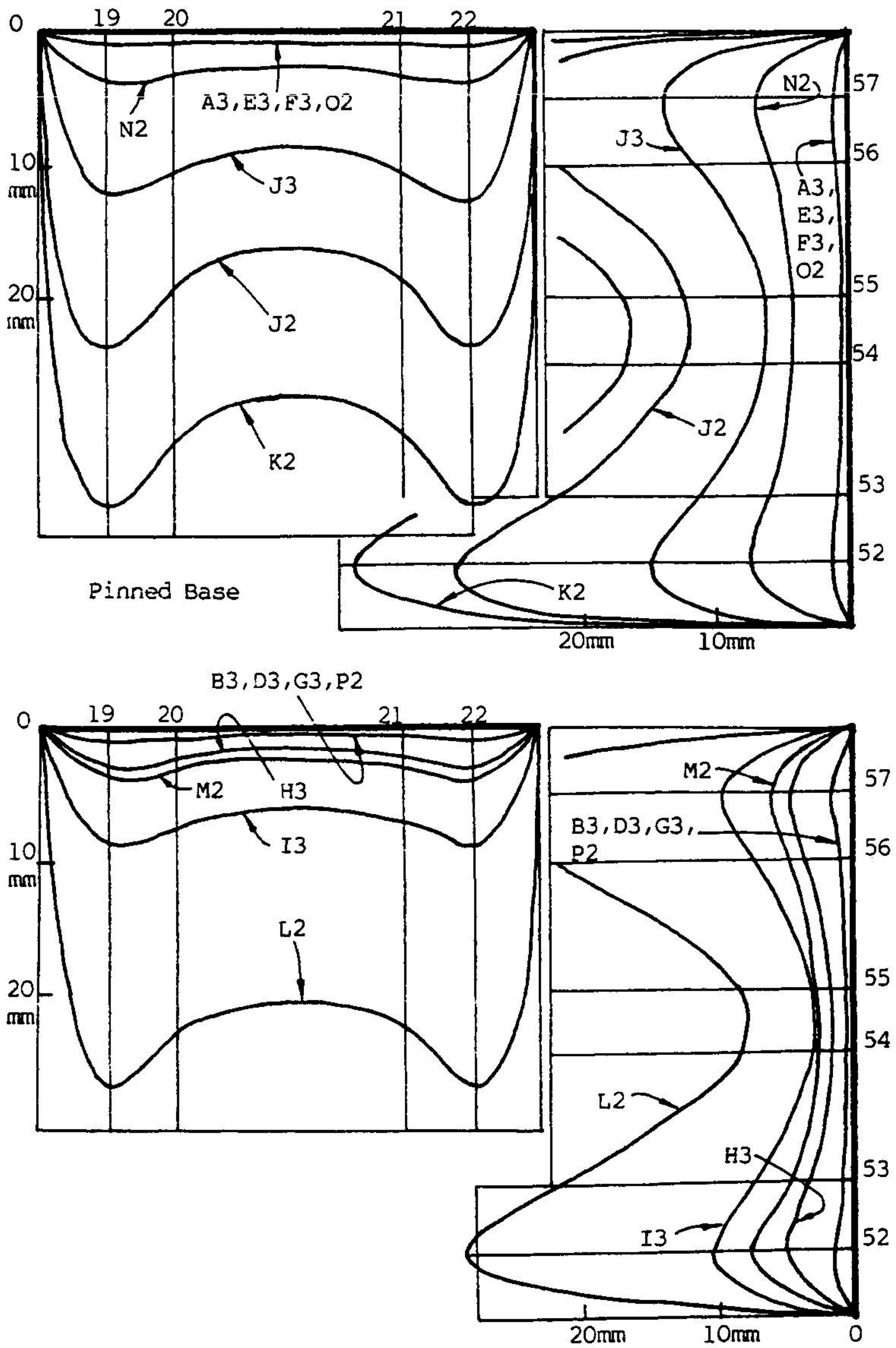


Fig. 3 Horizontal deflections along lines 19-22 and 52-57

3. RESERVE STRENGTH OF CRACKED WALLS

3.1 Assumptions of the Theoretical Analysis

As mentioned in Chapter 2, this theoretical analysis of the sheath is valid only if the thin sheath is prevented from buckling. In the previous application of the method to the vertical extension of old buildings, the masonry walls were not damaged and this was a valid assumption. If, however, the masonry wall is cracked, then the buckling of the thin sheath is more difficult to predict, as it depends on the reserve strength of the cracked wall to which it is tied, and the lateral support it can receive from such a wall behind it.

3.2 Experimental Approach

In order to determine the reserve strength of masonry walls with diagonal cracking, model brick walls were built at a scale of 1/8 and tested to failure. The model bricks, 50 mm x100 mm x40 mm thick and 50 mm x50 mm x40 mm thick, were cut from real brick pavers with a very high compressive strength of over 48 N/sq mm. This was deliberate to ensure that failure in all cases would occur at mortar joints, as is more common in practice. A premixed, cement/lime/sand "N" mortar with a specified compressive strength of about 5 N/sq mm was used for laying the model bricks, 18 courses high, in an English bond, with mortar joints about 6-8 mm thick. With 18 courses, the test walls had dimensions of 210 mmx50 mmx830 mm giving a very high h/t ratio of 16.6. The purpose of a high h/t ratio was to ensure that failure of the walls in all cases occurred in compressive buckling and not in crushing. Testing was carried out in a structural steel testing frame with hydraulic actuators (jacks) applying the vertical load. To build a cracked wall, the mortar joints while still green were wire-cut in a stepped, diagonal X pattern, with three such X patterns in the wall height of 830 mm. The entire wall was thus separated into 10 sections as shown in Fig. 4. After 7 days curing the cracked wall was reassembled and tested to failure as shown in Fig. 5. The results of the tests are shown in Table 3.

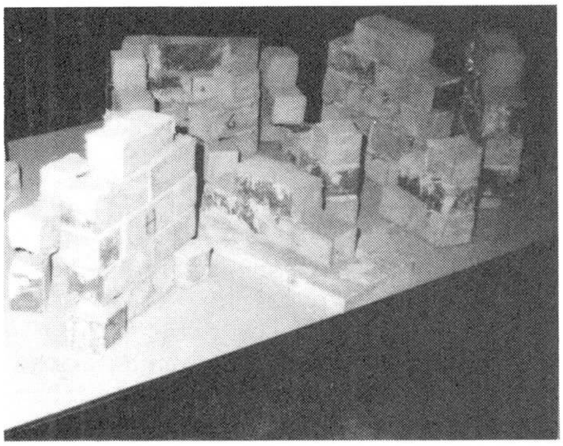


Fig. 4 Cracked wall in sections

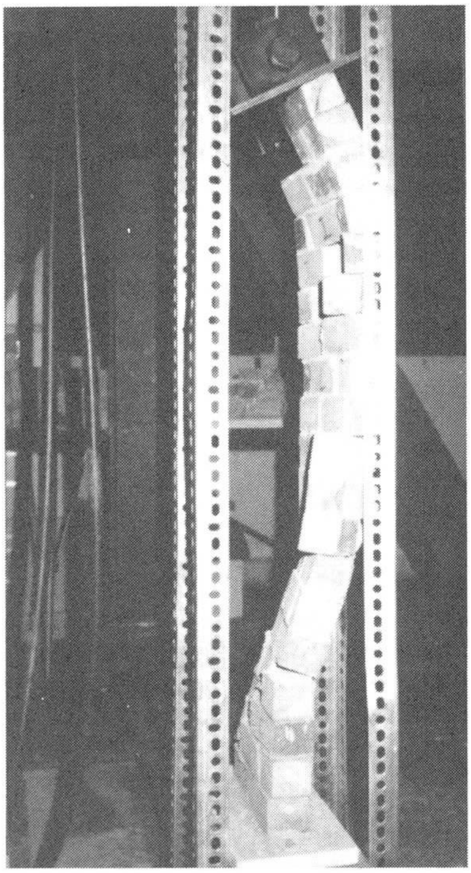


Fig. 5 Cracked wall at collapse

Type of wall	Actual load kN	Load when reduced to pinned ends, kN
Uncracked	43.66	43.66
Uncracked	58.95	58.95
Uncracked	41.48	165.92
Cracked	26.20	26.20
Cracked	32.75	32.75
Cracked	21.83	21.83
With Sheath	22.92	91.68
With Sheath	25.11	100.44

Table 3 Buckling failure loads of the walls

4. SHEATH TIED TO THE CRACKED WALL

A cracked wall was first built as described in 3.2, with, however, 34 ties embedded into the mortar. The ties were screws, 5 mm dia. and 64 mm long. Wing nuts were used when the mortar had set. Fine wire mesh reinforcement was tied to the bolt heads and the cracked wall assembled against a sheet steel form covered with plastic wrap. To prevent leakage, the wall was taped to the form; nevertheless, some leakage did occur. The wall was still a cracked wall, as seen in Fig. 6. A flowable mix was used, yet the walls still required some patching with the same grout. The thickness of the sheath varied from 6 mm, at sections where failure occurred, to a maximum of 12 mm. These walls were tested with end conditions of fixed at the base and free at the top, to stay within the load capacity of the actuator. The results are shown in Table 3.

Fig. 6 Cracked wall with sheath

Fig. 7 Sheath at collapse

5. CONCLUSIONS

This research shows that even severely damaged masonry walls can provide lateral support to the thin, reinforced concrete sheath to prevent buckling. The cracked wall has about 30% of the strength of the uncracked wall, and the provision of the sheath returns the structure to 107% of its original strength. Furthermore, whereas both uncracked and cracked walls showed explosive failure in the mortar joints, the cracked wall with the sheath showed a non-explosive failure along a single line of weakness, as shown in Fig. 7.

6. ACKNOWLEDGEMENTS

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