A MINE SUBSIDENCE RESISTANT MASONRY HOUSING SYSTEM

R.J. White¹ and A.W. Page²

1. ABSTRACT

This paper describes a series of tests which were carried out at the University of Newcastle to investigate the behaviour of a purpose-designed masonry residence when subjected to the deformations of a longwall mining event and subsequent re-levelling. The tests are equally indicative of the behaviour of the structure when subjected to reactive soil curvatures. The project aimed specifically at designing and testing a system of masonry construction which could withstand the effects of the ground movements induced by mine subsidence without being damaged. This paper gives a brief history and background to the project, and then describes the design philosophy and criteria, the construction methods, the testing procedures, and the results.

2. INTRODUCTION

Underground mining is extensively carried out in many areas of the world. In the Hunter Valley of New South Wales, Australia, underground coal mining is a major economic activity. Differential ground movements produced at the ground surface by this mining can cause damage to structures sited within the affected area.

To control the problem of damage due to mine subsidence two approaches are taken. The first is to restrict ground movements by placing a limit on the amount of permissible extraction by leaving pillars. The second is to restrict the type of construction in undermined areas to less brittle materials such as timber framing with timber cladding. The former strategy results in the sterilisation of significant volumes of coal; the latter strategy does not suit the community nor the developer, both of whom often want to use masonry construction.

A second cause of ground movement, and subsequent masonry damage, is shrinking and swelling of reactive scils. The curvatures induced by this phenomenon are the main source of damage, and these are similar to those produced by mine subsidence. A system which solves one problem may therefore solve both.

Keywords: Masonry; Housing; Mine Subsidence; Reactive Soils.

¹ Consulting Engineer and Postgraduate Student
² CBPI Professor in Structural Clay Brickwork, Department of Civil, Surveying and Environmental Engineering, The University of Newcastle, Callaghan, NSW, 2308, Australia
Much of the research on masonry structures subjected to ground movement has been directed at element behaviour, e.g., footings, footing/soil interaction, or walls. This project considered the performance of the complete house as a structural system. That is, the overall performance of the structure combined with that of its components. A complete house was constructed using the system which was developed, and this house was subjected to a series of simulated mine subsidence events to verify its satisfactory performance.

3. BACKGROUND TO THE PROJECT

Newcastle has a long history of mine subsidence problems, as it is substantially undermined by early coal workings. In more recent times, the conventional bord and pillar methods have given way to longwall mining in which all the coal in a seam is extracted causing immediate surface subsidence. There is therefore a need to develop masonry housing systems which are capable of absorbing the effects of random "pot hole" subsidence from existing workings; or ground strains, tilts, and curvatures induced by new longwall mining. If designed and detailed correctly, the same system should also be capable of withstanding the effects of the shrinkage or swelling of reactive clays (which produce similar ground curvatures), as well as the forces induced by extreme loadings from wind or earthquake.

The aim of the project was therefore to develop a residential building system of masonry construction which could withstand the effects of longwall mining, highly reactive clays, earthquakes, and extreme winds. In technical terms the system needed to be capable of withstanding the effects of severe ground curvatures, ground strains, and lateral forces, and of being lifted from the outside only after a mine subsidence event (for re-leveling), without there being significant resultant damage to either structural or architectural elements. It was also important that the system did not restrict the architectural design freedom.

Initially attempts were made to organise the construction of a house on land which was scheduled to be undermined. Numerous problems were encountered, including timing of the undermining, obtaining the required subsidence parameters, the lack of repeatability of the experiment (only one set of results could be obtained), local geological problems affecting the nature of the subsidence, and the location of suitable land with commercial value for subsequent sale of the house.

It was therefore decided to construct the house on a jacking system and simulate the ground curvatures. Testing in this way eliminated the problems above, gave complete control of the applied deformations, and resulted in far more information relevant to other research programmes being produced.

The University of Newcastle agreed to the tests being done on a cottage that was being planned on campus for the warden of Evatt House, one of its residential colleges. A suitable testing system therefore had to be developed to suit the architectural design, with due allowance for repairs if necessary. The additional costs of testing were offset by project sponsorship, with the net cost of the house for the University remaining the same.

4. EXTERNAL EFFECTS

The external effects included in the design of the structure related predominantly to longwall mining and reactive soil movement. Other loads such as wind and earthquake were also considered.

4.1 Longwall Subsidence

In a typical longwall mining situation, the ground surface, while subsiding, also undergoes a wave motion as the mine passes beneath (see Figure 1). The ground surface
firstly curves downwards, in a half-crest like curve, placing the ground surface in tension. Then it curves back the other way, in a half-trough like curve, placing the ground surface in compression until it levels out. The final ground levels will be much lower than the original, with the drop in level being a function of the thickness of the seam which has been removed. The house will also often finish out of level if it is located on the edges of the subsidence area.

It is ground curvature that causes most of the damage to masonry walls, which are brittle. The total amount of subsidence (i.e., rigid body movement) is of little significance in this respect.

4.2 Reactive Soil Movement

Reactive soil movement is due to shrinkage and swelling of clays with increases and decreases in moisture content. The point to note is that this movement creates curvature of the ground surface due to variations in moisture content between the underside of the outside of the house, which is affected by soil moisture changes, to the underside of the middle of the house, which is relatively stable. The affects on the residence are the same as for curvatures due to mine subsidence (see Figure 2).
5. TEST HOUSE

5.1 Design Philosophy

Two different design philosophies can be used to cater for the effects of ground curvature (see Figure 3).

The first is to make the structure sufficiently stiff that it does not follow the ground curvature. This may involve the slab alone, or the slab/wall system may also be designed as a series of stiff composite structural elements. Since there is no induced curvature in the masonry, there should be no cracks induced. The second philosophy is to allow the structure to move freely and to minimise stresses in the masonry by suitable articulation and other detailing.

Both approaches have merit. The second philosophy was chosen because it was felt that the additional attention to detail required for this method would be cheaper than a stiffer slab and reinforced walls. In addition, the low stress levels in the masonry results in a more fool proof design approach when the system is in use, with damage only resulting from poor workmanship or detailing which can be easily controlled.

5.2 Design Criteria

The most damaging factor in both mine subsidence and reactive soil movement is ground curvature. The tests were therefore designed to simulate these ground curvatures. The ability of the system to withstand lateral loads from earthquake or high winds can be justified by routine calculation, so that no testing was considered necessary for these situations.

The following subsidence parameters were simulated:

- ground curvature of 900 m radius
- residual tilt of 10 mm/m
- horizontal strains were assumed to be eliminated by suitable detailing (for example, the footings can be isolated from the surrounding soil by sand layers and flexible packing at the points of footing–soil contact).

The degree of articulation used in the design of masonry was consistent with current Australian practice for the design of masonry to remain uncracked when subjected to highly reactive soils. Joints were therefore designed to accommodate an induced curvature of 900 m with maximum articulation joint spacings of 5000 mm.

5.3 Housing System

As described earlier, a full scale prototype house was constructed on the University campus. The house was a single storey three bedroom dwelling constructed in full masonry with a metal roof. It was L shaped in plan (16 m × 12 m), with a prestressed concrete raft slab, a light steel frame consisting of rectangular hollow section (RHS) columns and roof ring beam, steel trussed roof, and masonry external and internal walls. The external walls were non-loadbearing cavity brickwork walls and single skinned autoclaved aerated concrete (AAC), with the different systems being used in different locations to check their effectiveness. All walls were articulated at 5500 mm maximum centres, all supported by the RHS columns with specially developed flexible ties capable of accommodating the appropriate movements. One masonry panel in each external wall was designed to act as a shear wall, and was attached to the columns with rigid ties. All external walls were rendered externally and covered with plaster board internally.
Figure 3. Alternative Design Approaches for Ground Movements

Figure 4. Slab Plan and Jacking Points
Internal walls were both brickwork and AAC, covered on both sides with plaster board. Since the internal walls were also non-loadbearing, suitable movement joints were detailed wall-to-wall and wall-to-ceiling to accommodate movements.

A series of pads and pockets were built beneath the concrete slab to allow jacking of the structure once it was completed. There were seventeen jacking positions in all, thirteen around the perimeter, and four internally. The floor plan of the test house and the jacking locations are shown in Figure 4.

Lateral stability for the structure was provided by a shear wall panel in each external wall, combined with a rigid masonry core formed by the bathroom walls, with the two systems being inter-connected by a ceiling diaphragm (see Figure 5). Because the structure was to be subjected to both ground curvatures and tilts, the following additional features were also incorporated to accommodate movement and minimise damage:

- a pin jointed structural frame, with provision for rotation between the columns and the ring beam, as well as rotation of the trusses at their connection, the ring beam, and at their apex.
- a ceiling system which was independent of the walls so that the walls were laterally restrained against movement but permitted to move vertically into the ceiling space.
- flexible joints in plaster board lining at wall corners.
- flexible adhesive between wall linings and tiles and the masonry.

Figure 5. Shear Panels and Ceiling Diaphragm
(SP = Masonry Shear Wall Panels)
• a bond breaker between the slab and all walls.
• compressible non-masonry panels above doors.
• tie connectors across the top of windows to connect adjacent masonry wall panels.
• location of electrical and plumbing services in the ceiling and walls rather than in the slab.
• flexible external connections of sewerage and water lines to allow for vertical movements between the slab and the ground.

The house was tiled and partially rendered prior to testing so that all the brittle elements were included in the test. It is also significant that the house was not designed to avoid problems. It was designed architecturally prior to any thought of using it for this project. The use of an L shape and a central cathedral ceiling were features which challenged the system. However, it confirmed that the system does not restrict architectural design freedom.

5.4 Behaviour of the System

• During a Mine Subsidence Event

The structure is designed to be flexible and follow the ground curvatures. The sides of the shear panels will remain perpendicular to the slope of the slab beneath them. This means that all columns in the frame, since they are linked at the top, will be parallel to the columns adjacent to the shear panel (and not perpendicular to the slab beneath them). The sides of the infill wall panels, however, will all be perpendicular to the slab beneath them. Sufficient gaps were left between the frame columns and the adjoining infill walls so that they would not be in contact when the ground was at maximum curvature.

The width of articulation joints between adjacent masonry wall panels were sufficiently large that they did not close up at maximum ground curvature.

Walls perpendicular to the direction of curvature were connected to the frame columns so that they could move with them. Similarly, the ceiling was supported by the structural frame and therefore moved with the frame columns.

The slab was inherently strong enough to resist high ground strains.

• During Re-Levelling

The structure was capable of being lifted from the outside only, and therefore being re-levelled whenever necessary, without damage. This effect was similar to that occurring during a subsidence event, as described above.

• Earthquake or Wind Forces

With the system lateral loads are transferred by all external walls, in out-of-plane bending, to the structural frame. The frame transfers the loads to the ground via the ceiling plane bracing. Uplift is resisted by the frame being tied down with masonry anchors through the column baseplates to the slab. This is particularly important at the shear wall columns.

• Preliminary Testing

A series of laboratory tests were carried out prior to the house construction, to gain
information on the performance of various components and confirm the performance of various connection details. These involved a number of racking tests on AAC and brick shear panels, tests on the flexible brick ties, and plasterboard fixing. This was particularly important for the resolution of the performance and practicality of details.

5.5 Testing Procedure

The jacking was performed on the completed house, off the concrete pads placed at approximately 4 m centres beneath the floor slab (see Figure 4). The jacks were hydraulically operated and individually controlled for displacement. They could therefore be individually raised and lowered as required to simulate the curvature and tilt of a subsidence event. The displacements at each jacking location were monitored using water levels located adjacent to each position. More accurate monitoring of the slab profile and the rigid body movement of walls and the tops of columns was carried out using precise levelling and a “total station” capable of tracking the three dimensional location of any point. The opening and closing of control joints was also monitored electronically. A typical jacking location is shown in Figure 6.

Using seventeen jacks, as shown in Figure 4, a series of waves were simulated passing under the house. The jacks were lifted simultaneously, but by different amounts in each row. A circular arc was therefore achieved. A number of separate stages was needed, tightening the radius of curvature at each stage, until the final radius of 900 m was achieved.

Figure 6. Typical Jacking Location
The sequence was the same as the house would be experiencing during the subsidence event. Firstly the tension ("doming") curve was simulated by lifting in the centre rows. Then the slab was levelled out. Then a compression ("dishing") curve was achieved by lifting on the outside edges, and then the house was again lowered to level.

This process was repeated three times – passing a wave in the north/south direction, then the east/west direction and finally across the diagonal at 45 degrees.

The final test was to show that the house could be re-levelled by jacking from the outside only. The jack spacing was increased to 6 m centres. The house was then lifted to a tilt of 10 mm per metre and then lowered. There was no damage during this process with the slab curvature being minimal. Since the slab was pivoting about one edge at this stage with the remainder being off the ground, it would not have mattered what the tilt had been taken to, the result would still have been no damage.

6. RESULTS AND DISCUSSION

No significant damage was observed in any of the tests described above, indicating that the masonry housing system was capable of withstanding a subsidence event. Some minor cracks in the masonry occurred in a couple of isolated locations, but these closed up once the imposed curvatures were released. There was some minor damage to the internal plaster board (as expected), and no damage to tiles or render.

For the system to have performed successfully it was necessary that the only residual damage be cracking of the plaster board joints. This would mean that, after a subsidence event, the only repairs required by the Mine Subsidence Board would be re-setting these joints and painting. The testing was therefore 100% successful.

There was damage to the plaster board above the lounge room openings but this was as expected. Joints were designed for these areas, but it was decided to omit them to see if the flexibility of the plaster board adhesive was enough to avoid having joints. It is of interest to note that there was no damage to plaster board at all until half way through the compression wave.

All the articulation joints performed satisfactorily with the observed movements being as predicted. A longitudinal crack was observed in the prestressed floor slab in the "doming" configuration, but this crack closed once the slab curvature was removed.

7. CONCLUSION

This paper has described a masonry housing system which is capable of withstanding the effects of a longwall mining event ("doming" and "dishing" curvatures as well as residual tilt). The curvatures induced were of the same order as those produced by the differential drying effects of reactive soils, indicating that the system would also be suitable for reactive soil areas.

The housing system consists of a prestressed concrete raft slab, and a light steel framing system, combined with masonry external and internal walls. The system is detailed so that the movements between the articulated masonry elements are accommodated by the flexible attachments to the supporting frame. Lateral stability is provided by masonry shear walls in conjunction with a ceiling diaphragm system.

The series of tests simulated a range of surface curvatures and tilts, and no tests produced any significant distress in the masonry or other walling components. The system therefore has the potential to provide a full masonry housing system for use in subsidence areas in which only flexible, lightweight construction would normally be allowed.
8. ACKNOWLEDGMENTS

This project was a joint undertaking of the University of Newcastle and Masonry Developments Pty Ltd.

This project was only successful because of the support of the staff of the University of Newcastle, the Mine Subsidence Board, and the various sponsors of the project. Their support is gratefully acknowledged. In particular the assistance of the staff and postgraduate students of the Department of Civil, Surveying and Environmental Engineering during the tests is also gratefully acknowledged.