Investigation and stabilisation of Chester city walls

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ABSTRACT

Chester city walls have suffered throughout their life from continuing movement and by the late 1980's there was considerable concern for their stability. The paper describes the archaeological and engineering investigations, the knowledge gained on the structural history of the wall and the current causes for its instability.

INTRODUCTION

The Chester City Walls, are of international and historic importance, forming a complete circuit around the inner city. The walls have been adapted and developed throughout history in places preserving sections of the Roman fortress wall adjacent to and beneath medieval and Victorian construction.

The City has a regular maintenance and monitoring programme for the walls and in 1988 it was apparent that two particular sections of the wall were suffering from continuing inward movement and that this was now giving cause for concern. The City appointed Gifford and Partners to investigate the movement of the walls.

THE HISTORY OF THE CITY WALLS

The city walls are a splendid record of the history of Chester being repaired, rebuilt and adapted ever since their original construction in the last first century AD by the Romans, as the needs of the citizens of Chester have changed. The documentary records are necessarily scarce, but detailed work by City Archaeologists over the last 100 years have steadily pieced together a fascinating record. The ancient Roman fortress walls were constructed in the first century consisting of a turf rampart surmounted by a wooden palisade and towers with an external ditch. During the second and third centuries a red sandstone curtain wall was constructed in front of the turf rampart, greatly improving the defensive capability of the fortress and its grandeur. The ditch was recut and the rampart wall reshaped. During the Saxon period the wall fell into disrepair and in due course in the medieval period the west and south walls of the fortress were partially removed and the wall rebuilt closer to the river to extend the enclosed area of the city. During the 13th century the medieval city wall was built on top of the existing Roman wall where it remained in

reasonable condition and in other areas adjacent to it. The wall was hastily refortified during the civil war and in the early 18th century was restored and at this time made into a walk for the citizens as opposed to a defensive structure. In the late 19th century there was a significant collapse on the north wall and large scale reconstruction took place.

INVESTIGATIONS

1. Desk Study and Archive Search - The City archive and the investigations carried out by the city archaeological unit were inspected. This revealed a mass of background information including records of the restoration works on the north wall in the 1880's, from which it was clear that the internal structure of the wall was complex as a result of constant maintenance and repair over the centuries, though with no detailed records.

2. Perusal and Topographical Survey - A detailed visual inspection of the walls was carried out in conjunction with a detailed topographical survey, recording all relevant information.

3. Photogrammetry - Photogrammetric survey drawings were made which carefully checked, interpreted and corrected.

4. Previous Repairs, Statutory Authorities and Ground Conditions - The work over recent years consisted of repointing and local rebuilding of small areas of face masonry. The east wall at the Kaleyards had been pressure grouted in the early 1980's and stainless steel ties inserted between the internal and external leaves. The monitoring of the walls showed that the movement of the east wall was still continuing, although the whole wall was now rotating inwards, not just the internal leaf. The monitoring of the north wall showed that there was a continued, and possibly increasing, rotation of the whole wall to the south. In both areas the extent of the tilt of the wall was noticeable and becoming a subject of public discussion. The statutory authorities records were checked to determine the locations of any services close to the wall. Finally, the records of soil conditions in the area were checked.

5. Assessment of Initial Investigation - The information from these initial investigations was compiled and the sequence of construction of the walls, the variations in loading and the environmental effects upon it assessed. However it was clear that we had insufficient information on the real structure of the wall, its foundation and underlying soil conditions. A number of further techniques were then considered for obtaining this information including: radar surveys of the wall, trial borings, horizontally and vertically. However these would not provide the level of information necessary. It was agreed that cross sectional excavations should be made through the wall to foundation level, to record all necessary archaeological and engineering information.

CROSS SECTIONAL EXCAVATION THROUGH THE WALLS

The City walls are a scheduled monument and therefore formal consent was required prior to any work being carried out. Consultation took place between the City, English Heritage, the City Archaeologist and our own engineers and archaeologists in order to determine the nature of the work, the method of carrying it out and the information that was to be recorded. The following sequence of work was agreed for two excavations through the wall; one in the North Wall and the other adjacent to the Kaleyard gate:-

1. A scaffold was erected enclosing the wall and tented to provide weather protection.
2. Each stone was numbered with chalk on its face and a dimensional record of its position in the horizontal plane taken. In conjunction with the photogrammetric survey, this provided a three dimension location of each stone.
3. The walls were dismantled in layers with the fill being excavated and recorded archaeologically in 2 m layers prior to dismantling of the external faces.
4. The facing stonework was then dismantled, cleaned, a reference number carved into its top face and stored on pallets off the ground adjacent to the wall.
5. This procedure was continued until the top of the masonry of Roman origin was reached, when the facework was left intact and other internal masonry and fill was dismantled to foundation level of the external wall. If this did not coincide with bedrock, hand auger boreholes were taken to establish the level of bedrock below the foundation.
6. Detailed archaeological recording was carried out on all materials found and samples taken for analysis, which was not only for its engineering properties, but for environmental conditions e.g pollen analysis. Figure 1 shows a typical example of a recorded cross section.
7. Rebuilding of the wall commenced, replacing each stone in its original position, in 1 m lifts before backfilling the core of the walls with well compacted imported coarse sandstone.
8. Inevitably a few stones were damaged during the works. This was often due to small patch repairs having been made to the facework with high strength mortar at some stage in the past so that dismantling of the stonework resulted in split stones rather than breaking of the mortar bond. Fractured stones were repaired with Akemi epoxy resin. The mortar used for the reconstruction of the facework was 1:1:5 slaked lime/cement/sharp building sand. Where any repointing was necessary a 1:1:1:5 mortar was used on slaked lime/portland cement/grit/sharp building sand.
9. To improve the integrity of the wall in the short sections being reconstructed, a Fortrac geogrid was incorporated into the rebuild. The geogrid being bedded into the

masonry at approximately 450 mm lifts, tying the leaves together and knitting with the fill, hence providing a "soft" tie.

RESULTS OF THE INVESTIGATION

The detailed records allowed a "structural history" of the wall to be proposed. This is illustrated in condensed form in Figure 2.

The turf rampart remains a significant element in the city wall, though much buried and modified. The Roman masonry of the external leaf similarly survives to much of its original height though again buried and partially rebuilt. The medieval wall was perched on top of these remains and further patched and built upon during the Victorian period. The wall can be seen to be a collection of disparate elements only poorly tied together, but acting as a fascinating record of Chester's history.

The foundations to the external leaf is the original Roman foundation, consisting of coarse material built directly from the sandstone bedrock approximately 1.6 m wide by 0.7 m deep. The internal leaf foundation is of rubble fill on sandy clayey soils above the remains of the turf rampart, which is now a stiff low permeability material. The founding level is approx. 3 m above bedrock and approx. 2 m above the external leaf foundation. (3 m at Kaleyards).

The ground levels vary from internal to external faces of the wall, however the variation at the north wall is only 0.5 m while that at the east wall it varies between 1.3 and 2 m. It is clear from the interpretation of the wall structure that the ground levels have changed significantly over the years.

The original turf rampart was built of regular turves, with a rubble core and the structure tied together with logs and strapping at approximately ½ m intervals. The Romans were therefore using reinforced earth in the first century AD.

The masonry used in the wall is a local red sandstone with a compressive strength of around 17 N/mm^2. The Roman walls consist of good quality stone laid on natural bed in blocks typically 0.7 x 0.7 x 0.3 m and laid without mortar. The wall was originally 6 m high with pediment and cornice and was an imposing structure. The medieval wall above Roman level is generally more slender with large joints, the thickness of the stones being approximately 200 mm. The coursing is not regular and the sandstone is a poorer quality than the Roman and has weathered considerably. This is partly due to the sloping profile of the wall, which

has encouraged weathering and the growth of vegetation. The mortar in this element of the wall was found to be a 1:3 cement:sand mix and has obviously been repointed/reconstructed over the years. The internal wall also consists of smaller stones approximately 200 mm thick and on the north face the fill behind the wall was grouted to a depth of approximately 1 m, i.e the gap between the medieval wall and the Victorian wall, which increased the stiffness of the face. The size of the stones is inconsistent and the coursing is not regular with some stones laid perpendicular to their natural bed.

The fill was generally large sandstone rubble of varying sizes in a matrix of smaller broken sandstone and sandy soil, though poorly graded with little medium size content. The compaction of the fill varied and at the north wall there were a large number of voids that seemed to be a result of the outward movement of the wall faces. At the Kaleyards as a result of the grouting in 1983 no voids were present.

The walkway generally had a good cross fall with an overhang to the internal leaf and was generally well pointed, so that rainwater runoff escaped rapidly and the fill was dry with little evidence of water penetration.

ASSESSMENT

It is crucial to the understanding of the present state of the walls that their history be kept firmly in mind, as they have suffered collapse, rebuilding and renovation ever since 200 AD. It is abundantly clear that the investigative sectional cuts through the wall were the only way that sufficient information could be discovered and that the very close collaboration between archaeologists and engineers was essential for an understanding of the significance of the results.

The factors affecting the stability are: the continuing settlement of the foundations, the wall rotation, the eccentricities of the external masonry wall faces, their slenderness, the changes in loading on the walls, alterations to the groundwater regime, environmental effects such as frost, pollution and chemical action. It became clear during the assessment that no one cause for the settlement existed, but that the reason for the instability was a combination of events. The initial cause for the movement perhaps no longer existing but the result of the original cause, in combination with other changes, is now resulting in ongoing movements.

The primary cause of the current movement is that the wall has a combination of eccentric

loadings due to the original Roman wall being out of plumb, the movements being exacerbated by differential foundation settlements between the inner and outer leaves. The eccentric loading on the structure has resulted in secondary local movements causing some bowing of the external masonry leaves, causing voids to open up in the fill. This reduces the composite action of the wall so causing sections of the external leaves to act as independent retaining walls and for this they are inadequate, resulting in further movement. The secondary movements are causing a redistribution of the load within the wall such that the majority of the external leaf and the fill is leaning on the internal leaf. A small and gradual increase in load on the internal leaf is therefore occurring resulting in a small and gradual load increase to the foundation and hence a small and gradual increase in its settlement.

These movements are further stimulated over time by traffic vibrations applying dynamic loading to the structure.

OPTIONS FOR STABILISATION

A number of options were considered:-

Do nothing and monitor.
Underpin the existing internal leaf foundation to bedrock using piles.
Grout up the fill.
Construct buttress to the walls.
Rebuild the internal leaf and provide a new foundation.
Rebuild the internal leaf on a new foundation and rebuild the eccentric parts of the external leaf.

A major consideration in assessing the options for repair to the walls, is that they are a record of the history of Chester. If therefore it was decided to restore to their original Roman, Medieval or Queen Ann condition, then there will be a major loss, as the wall becomes a reconstruction at one moment in time, rather than an ongoing record capable of reinterpretation in future times. The essential principal therefore is to carry out the minimum necessary work to provide stability and to preserve what is there in its current condition, deformations and inadequacies included wherever possible.

REMEDIAL WORKS CARRIED OUT

On one section of the North wall approximately 6 m long the external leaf was bulging clear of the internal fill. This length of wall being in a more severe condition than the rest of the

wall between Northgate Street and the inner ring road, it was therefore proposed to carefully dismantle and reconstruct this section of the external leaf more nearly in line with its original profile. The Roman masonry which was leaning severely was realigned vertically with the integration of long through stones back into the fill to tie the wall together. The medieval masonry was similarly reconstructed slightly more upright and with stainless steel tie rods located back into the fill at regular intervals. The continuing movement of the external wall was therefore halted, which should then prevent the continuing increase in load on the internal foundation. A regular system of monitoring was initiated on the whole of the north wall in order to record accurately any future movements of the wall.

The remedial options to the east wall were similar but the wall had a greater lean and a more insecure foundation to the internal wall. The recommended action was to rebuild a complete section of the wall over a length of 10 m with a rebuilding of the internal leaf with a new foundation over a further 10 m. This section of work is currently awaiting funding and will be carried out in due course.

CONCLUSIONS

Our participation in this work has reinforced my belief that in order to fully understand the structural action of ancient structures, it is crucial to have a feeling for the historical perspective and not to take judgements on limited current day information.

The synergy of structural engineers and archaeologists working together, with an understanding of each others requirements, is of great advantage in solving problems for the repair and maintenance of historic buildings. In addition to which one can gain fascinating insights into the construction techniques of our forbears.

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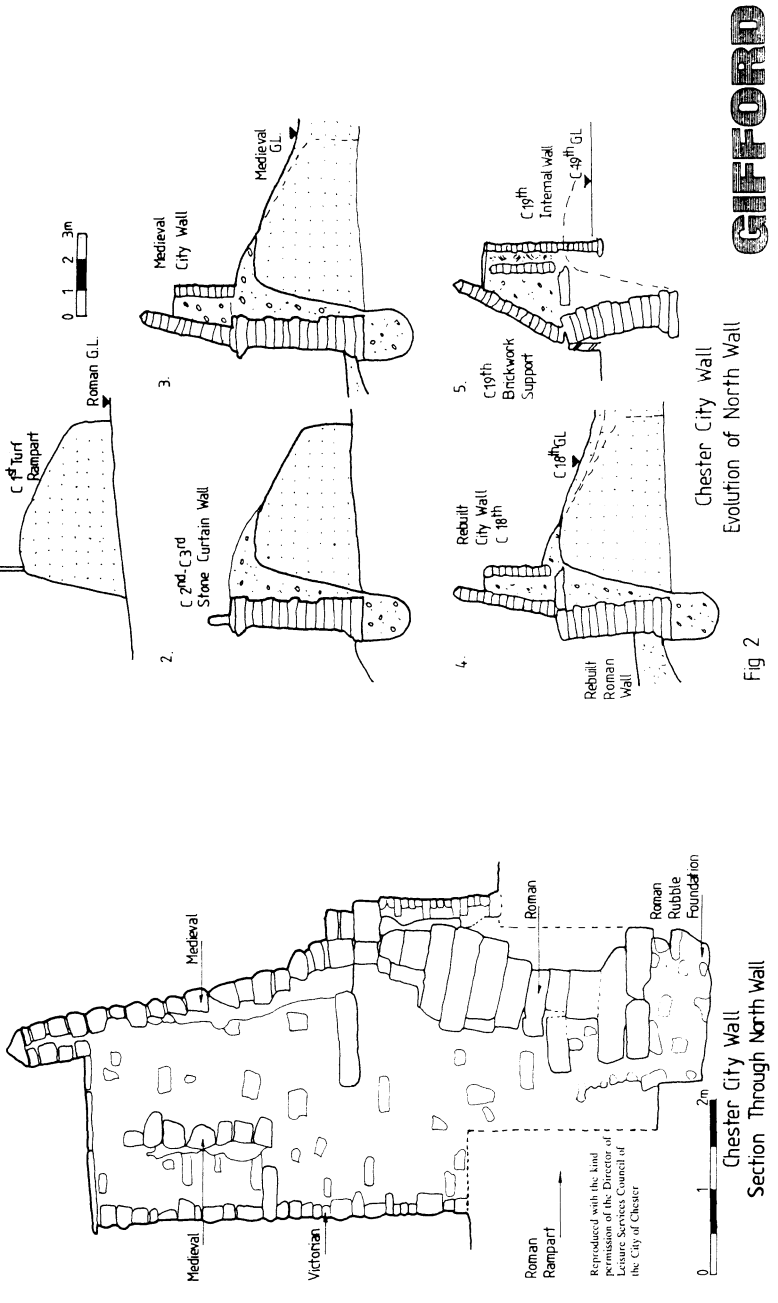
Chester City Wall
Section Through North Wall
Medieval
Victorian
Medieval
Roman
Roman Rampart
Roman Rubble Foundation
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0
1
2m
Fig 1
Chester City Wall
Evolution of North Wall
1.
Timber Defences
C 4th Turf Rampart
Roman G.L.
0 1 2 3m
2.
C 2nd-C 3rd Stone Curtain Wall
3.
Medieval City Wall
Medieval G.L.
4.
Rebuilt City Wall C 18th
C 18th GL
Rebuilt Roman Wall
5.
C 19th Brickwork Support
C 19th Internal wall
C 19th GL
GIFFORD
Fig 2