

Diagnosis and repair of cracking to an old 1880's concrete house for Channel 4 Television, UK

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ABSTRACT: Michael Grantham was initially approached in October 2010 by the owner of an old concrete house which was suffering from severe cracking. The house was due to feature on national television in a programme called "Help my House is Falling Down!" which is broadcast at prime time on Channel 4, one of the main UK TV channels. Subsequently, we were asked to appear on the programme and to conduct insitu and laboratory tests to determine the cause(s) of cracking and to help with remedial suggestions. The cause of cracking was very unusual and quite complex, resulting from a combination of expansion due to the use of old foundry waste as an aggregate and also due to cracking due to a lack of restraint in the walls.

This paper details the diagnostic work and also the remedial measures which were undertaken,

1 INTRODUCTION

Concrete is a fundamentally durable material, and has a good track record of successful use in building, provided it is of adequate quality, adequate protection of any reinforcement present has been provided and the structure is adequately designed to withstand the structural loads imposed on it, from either self weight (including the roof) and wind loading.

Occasionally, problems with concrete houses occur, in particular with some of the system built houses built before and after the second world war, including Laing Easiform, Airey Houses, Cornish Houses, Woolaway Houses and Wimpey No-Fines Concrete Houses. These, amongst other system built homes, were the subject of a report by the UK's Building Research Establishment (BRE, 2002) and each type of house was the subject of an individual report on appraisal and repair (Refs listed in BRE, 2002).

Other unusual problems have occurred in houses built with concrete blocks, where the aggregate used in the blocks was unsound. Materials which have caused problems in this respect include unburned coal, hard burned lime, iron pyrites (BRE, 1992 & 1997, RICS, 1997) and slag. The lead author has been involved in a number of such cases over the years, including a failure of houses at Snowdown in Kent and also a major problem involving failure of houses in Northern Ireland and the Isle of Man (both in the 1980's), which were due to the use of clinker aggregate in blocks where the coal contained limestone, which, when fired, became hard burned, slow

reacting quicklime. This material was moisture expansive and the result was massive cracking in the blocks resulting in cracking and expansion of the walls of the properties.

With this background, spotting one of the significant causes of problems at the house in the UK's Midlands, was made more easy. Other aspects of the failure were determined by the Chartered Engineer, Simon Pitchers, and also by a second structural engineer involved in the design of the remedial works, Frank Haywood Associates.

This paper discusses the investigation on site, performed while the programme was being filmed for television, the subsequent laboratory work and the remedial measures that have been adopted.

2 SITE INSPECTION

The visit to the property was made in November 2010. Inspection of the house externally revealed cracks up to 8mm in width, notably between the gable end wall and both the front and rear walls, where the gable end wall appeared to be moving outwards at the top and splitting away from the front and rear walls, more seriously so at the front (Figure 1).

Internally, the plaster had been removed from the upper rooms but was still present on those downstairs, rendering inspection of the hidden surfaces impossible. Upstairs, a band of severe cracking was present on the front and gable walls, about 1m deep at mid height in the wall (extending approximately from top to bottom of the window right round the

wall (Figure 2). Inspection of the rear bedroom showed a similar problem. It was possible to see daylight through some cracks!



Figure 1. House showing crack (inked over) between gable wall and front elevation



Figure 2. Internal cracking in concrete in upper wall

Further inspection in the loft of the property revealed similar cracking too, in the upper part of the gable end wall. More detailed inspection revealed an unusual fragment in one wall, apparently comprising a large lump (100mm or so wide) of what appeared to be “pig iron,” which was corroding. This was the first clue as to the cause of the unusual cracking.

In order to investigate further and to establish the comparative condition of the wall in the widely

cracked central band and the less fractured concrete above and below the more damaged zone, a series of tests was carried out. Initially we wanted to establish whether any reinforcement was present in the wall, so tests were performed using a Hilti Ferros-can® PS200 scanning covermeter (Figure 4). The procedures recommended in BS1881 Part 204 (BSI, 1988) were used for this testing. Six tests were then carried out with a Digital Schmidt Hammer (a Proceq Silver Schmidt®), following the procedures recommended in BS EN 12504-2 (BSI, 2001) and six tests were carried out in similar positions using a PUNDIT 6 Ultrasonic Pulse Velocity Testing machine. The procedures recommended in BS EN 12504-4 (BSI, 2004) were followed except that tests were conducted in indirect mode, owing to the difficulty of getting a path through the walls, because of the uneven surface of the external rendering. These tests were carried out at locations above, in the centre of and below the band of deteriorated concrete in the gable wall at 1st floor level, in the front bedroom. Figure 3 shows the arrangement of test locations.

Two 100mm diameter core samples were then removed by diamond drilling to enable samples to be sent to the laboratory for petrographic examination.

Gable Wall, 1st Floor, Test Locations and Heavily Deteriorated Band

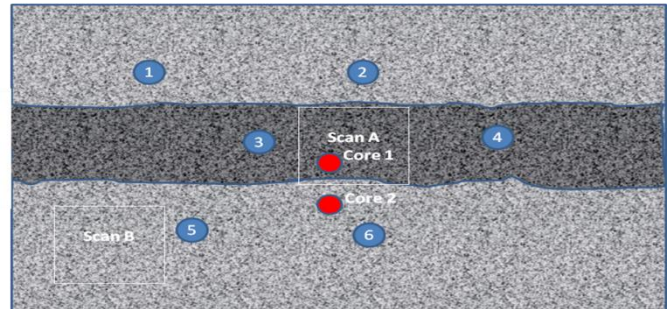


Figure 3. Schematic showing core sample and PUNDIT and Schmidt Hammer test locations

Table 1. Results of Schmidt hammer Tests

Schmidt Hammer Rebound Number	Test Position					
	No 1	No 2	No 3	No 4	No 5	No 6
43	55	30	13	25	35	
33	31	20	21	35	35	
53	30	24	20	16	36	
43	17	29	20	34	36	
49	53	25	19	14	28	
40	44	21	24	25	29	
45	58	15	33	38	58	
46	52	31	7	46	37	
55	44	23	27	43	31	
39	64	28	29	31	44	
38	58	28	28	29	32	
50	52	21	59	29	33	
Mean	45	47	25	25	30	36

Table 2. Results of indirect UPV tests

UPV	Path Length	Transit Time 1 us	Transit Time 2 us	Mean	UPV km/s
No 1	300	126.5	126.5	126.5	2.4
No 2	300	200.9	200.9	200.9	1.5
No 3	150	86.2	88.2	87.2	1.7
No 4	150	112.1	114.3	113.2	1.3
No 5	300	161.9	162.1	162.0	1.9
No 6	200	78.5	79.1	78.8	2.5

The test results were very interesting. It was not entirely clear whether some form of reinforcement was present in the walls, as was suggested by the Ferroskan® survey, and lack of time and the poor condition of the walls prevented exploratory cutting out to determine whether any was present. What the covermeter survey did reveal was the presence of numerous metallic lumps in the concrete, similar to that observed in one part of the wall in some areas.

The Schmidt Hammer values showed low results for positions 3 and 4 in the centre, deteriorated, band and interestingly also at Position 5, in the visually better concrete nearer to floor level.

The ultrasound results all showed rather poor quality concrete (good concrete would be expected to show values in the 4km/s region, or better). All tests were undertaken using indirect transmission (from the same side of the wall, rather than through it, as the rough surface of the pebbledash rendering made it impossible to take readings through the wall). The reliability of indirect readings is poorer than those using direct transmission.

Of special interest was the presence of several vertical cracks in the concrete underneath the heavily deteriorated band. These were a clear implication of expansive movement of the concrete in the deteriorated band, causing a tensile stress in the zone of concrete underneath (Figure 5)

3 LABORATORY TESTS

The two core samples were taken in the centre zone of the deteriorated concrete and in the better condition concrete beneath. The former was difficult to remove intact whereas the latter core showed good integrity. The petrographic testing was carried out in accordance with APG SR2 (Eden, 2010) and ASTM C856-04 (ASTM, 2004). In brief, the following work was carried out.

- The samples were examined as received and photographed.
- A longitudinal polished plate was prepared from each core selected for petrographic examination. The polished plates represented

the full depths of the samples and were orientated normal to the external surfaces.

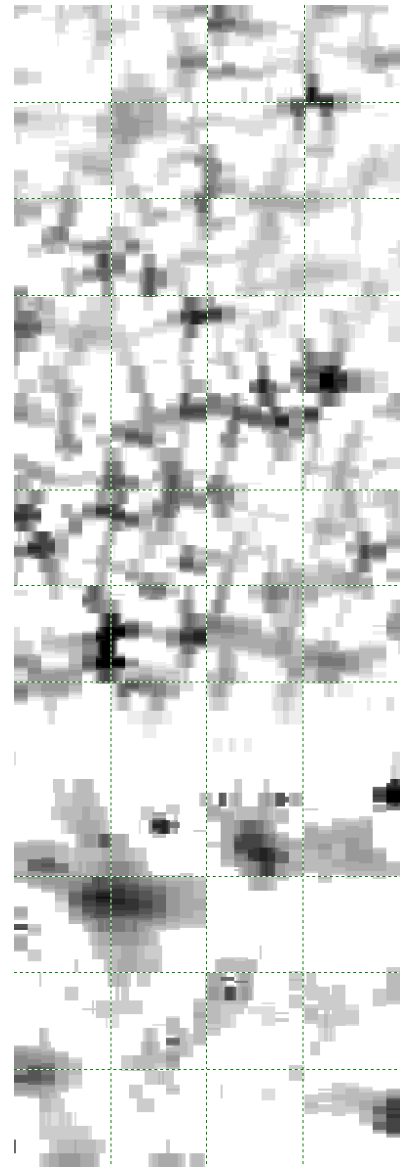


Figure 4. Three Ferroskan surveys (600mm x 600mm) one above the other on front elevation internal wall. Note the possible reinforcing mesh in the upper part and the apparent presence of iron fragments in the lower part.



Figure 5. Tensile crack (arrowed) in concrete below centre deteriorated band - the crack did not extend into the centre band.

- The volume proportions of aggregate, paste and void were determined by point counting of the polished plates using the stereo binocular microscope. The measured volume proportions were used in the calculation of the compositions of the samples using the method given in APG SR2 (2010).
- A longitudinal fluorescent resin impregnated thin section was prepared from the outer end of each sample selected for petrographic examination. The thin sections represented the samples between their external surfaces and maximum depths of about 70mm.
- The thin sections were examined with a Zeiss petrological photomicroscope and the distribution of porosity and microcracking was assessed from an examination of the thin sections in fluorescent light using the petrological microscope.

3.1 Core 1, deteriorated concrete in centre band

This had coarse aggregate that contained a very wide range of materials that included siliceous gravel, carbonaceous aggregate particles (coal/part-burnt coal/coke) and particles resembling slag. There were also metallic iron fragments and siliceous gravel. The iron particles were commonly corroded around their surfaces and corrosion-stained cracks sometimes appeared to originate from the metallic iron particles. Many of the aggregate particles in this sample were porous and weak.

3.2 Core 2, lower, intact concrete

The coarse aggregate was a siliceous gravel, together with some brick. The gravel contained abundant quartzite and vein quartz and was composed of dense and robust lithologies that were of low porosity. No evidence was found for the presence of slag, coal or coke in this sample. This sample had very few cracks.

3.3 Chemical tests

Chemical tests were also performed to determine total acid soluble chloride and sulphate using the procedures given in BS1881 Part 124 (BSI, 1988). The chloride levels were low in both samples at 0.004% of sample and low to normal sulphate contents were found, 0.09% and 0.31% respectively for deteriorated concrete in the centre band and the sound concrete underneath, respectively.

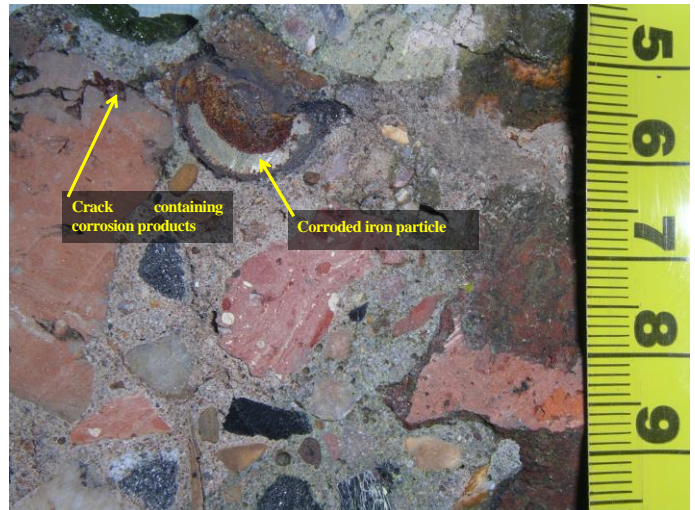


Figure 6. Corroding iron particle and associated cracking in deteriorated core.

The overall conclusion on the causes of cracking in the deteriorated concrete core was

- The weak and friable nature of the cement paste: This is regarded as being a result of a high water/cement ratio and also high void content / poor compaction.
- Metallic iron: The expansion associated with the corrosion of metallic iron accounted for some of the cracking in Core 1 (Figure 7). The observed large iron fragments seen at site were also considered to be a factor in more extensive cracking elsewhere in the structure.
- Coal / part burnt coal: The deteriorated core contained small amounts of coal and part-burnt coal particles. Coal particles are potentially capable of giving rise to expansive cracking when subjected to cycles of wetting and drying.

Overall, and following discussion with the consulting Engineers, Simon Pitchers and Frank Haywood, we concluded that the most likely cause of the cracking seen between the gable wall and front and rear elevations was most probably corrosion of the metal fragments in the concrete that had been placed in the lifts that were visibly damaged, causing a general expansion of these lifts in both a horizontal and vertical sense. The expansive action, that had occurred over a period in excess of 100 years, had caused the expanded sections to force the other elements of the fabric apart, which was entirely consistent with the cracking observed. More structural movement had followed caused by a lack of lateral restraint between the gable wall and the front and rear walls. The method of construction was partly responsible for this, where brick piers had been constructed in the corners to support the shuttering for the concrete, which had then been infilled afterwards, forming planes of weakness between the dissimilar materials

that were subsequently exploited by the expanding lifts of concrete..

4 REMEDIAL WORK

A considerable discussion on the best approach for repairing this structure was held, with the possibility of resin injecting the deteriorating cracked band of concrete, and hoping that would sufficiently restrict moisture and oxygen from fuelling further corrosion and expansion. This idea was rejected as there was not sufficient confidence that the moisture could not still find a way in. Furthermore it was evident that the extent of corrosion and expansion was slow (the house was 130 years old) and that keeping the structure dry plus dealing with the existing cracking and restraint issues would be the most appropriate method to prolong the life of the perimeter walls. These decisions were taken by the Consulting Engineers.

The final solution chosen involved providing additional lateral restraint using a combination of bow tie and helical stainless steel fixings between the gable wall and front and rear walls. These were installed in and around the positions of the most serious fractures in the external wall fabric.

In addition to this, cracks in the walls were sealed with resin injection, the walls were stripped of render and insulated cladding applied, followed by reinstatement of the rendering. Internally, the weak defective band of concrete on the first floor and also the weak material on the gable wall in the loft was removed to about 75mm depth in sections and replaced with a hand applied concrete repair mortar, allowing each insertion of repair material to set and harden, before proceeding with the next part. Finally, carbon fibre strips were added to walls to provide additional tensile strength to supplement the capability of the external wall to withstand wind pressures, prior to replastering.



Figure 7. Rendering removed and insulated cladding being installed



Figure 8. Helical stainless steel fixings to restrain gable wall



Figure 9. Carbon fibre strips glued in place with epoxy resin to provide additional strength to gable wall

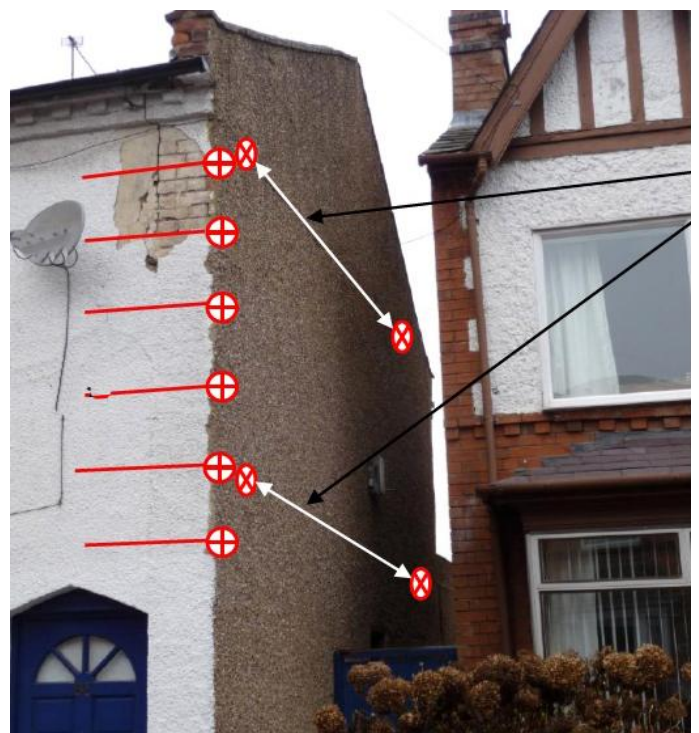


Figure 10 showing details of bow tie fixings at 600mm vertical centres (black arrows) tied into joists. 1200mm long CemTies installed through gable wall into both front and rear walls, generally at 450mm centres.

5 CONCLUSIONS

This project provided an extremely interesting challenge. Rarely do we get to work with concrete in such old structures, and the challenge of finding the causes of the defects was very interesting. Subsequent research showed that an iron foundry was operating quite near to the site, and it is likely that the opportunity for some easily available cheap infill material for the concrete was taken. Fortunately it appeared to have been used in selective lifts of the concrete, which rendered the problem containable, for the most part. Had it been used throughout the structure, the picture might have been very different. At that time, of course, the consequences of corrosion of the iron fragments had probably not been thought through by the contractor and concrete supplier. Modern engineers and contractors are only too well aware of the damage that corroding iron and steel can do to a structure.

The chosen remedial solution will extend the serviceable life of the building, by reducing the rate of corrosion of the embedded metal fragments that are the principle source of disruption to parts of the external leaf. The rendered insulation on the outside of the perimeter walling will prevent the ingress of rain from the outside and will increase the temperature of the concrete walling during cold spells, moving the dew point and reducing the tendency for condensation to form within the perimeter walling. The addition of a vapour check to the internal face of the perimeter walling would also control migration of water vapour into the perimeter concrete walls. Controlling water migration into the perimeter walling will reduce the rate of corrosion of the embedded metal fragments and will result in an extended serviceable life for the structure, further harnessing the intrinsic thermal mass of the perimeter walling.

These improvements, together with the structural strengthening will improve matters considerably for the structure.

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