The Results of the Investigations into the Possible Sulphate Attack

Relating to:

XXXXXXXXXX
XXXXXXXXXX
XXXXXXXXXX
XXXXXXX

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Project Preface

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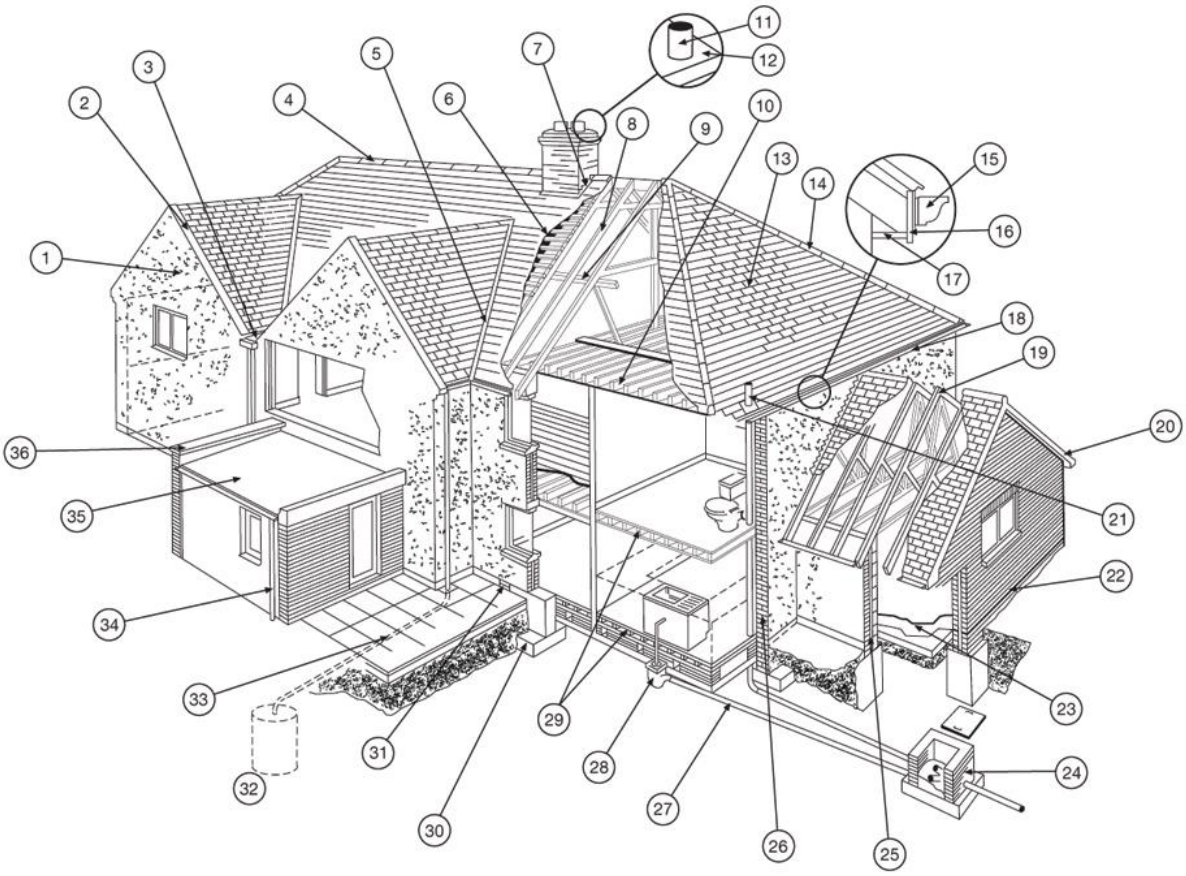
Traditional House Construction



KEY

1 Gable end wall
2 Verge
3 Valley gutter
4 Ridge tile
5 Valley
6 Roofing felt
7 Flashing
8 Rafter
9 Purlin
10 Ceiling joist
11 Pot
12 Cement

13 Hip roof
14 Hip tile
15 Gutter
16 Fascia
17 Soffit
18 Eaves
19 Roof truss
20 Barge board
21 Soil-and-vent pipe
22 Damp-proof course (DPC)
23 Damp-proof membrane (DPM)
24 Inspection chamber

25 Cavity wall
26 Solid Wall
27 Foul drain
28 Gulley
29 Floor joists
30 Foundation
31 Airbrick
32 Soakaway
33 Surface water drain to soakaway
34 Downpipe
35 Flat roof
36 Parapet

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1 Introduction

1.1 Instructions

In accordance with instructions received from XXXXXXXXX on XXXXXXXX we have carried out a Sulphate Investigation of the floors at the property known as XXXXXXXXXXXXXXXXXXX. The inspection was carried out on XXXXXXXXXXXXXX. All comments are based on visual inspection and trial excavation along with laboratory testing of recovered samples of both the concrete and the fill beneath the floor. No drainage survey has been undertaken.

1.2 Brief

We have been asked to carry out a sulphate attack investigation of the floors at the property due to the property being within an area where sulphate attack is common, consequently this report is restricted to the floor of the property only and no comment is made on any other part of the property, which was not the subject of this report.

This report is designed primarily for the purposes of house sales. In certain circumstances a more detailed investigation may be required.

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1.3 Site inspection

Where the terms “right hand” or “left hand” are used, they assume that the reader is facing the front of the property with the main access door situated within the left hand elevation

1.4 Drainage Survey

We are not aware whether a drainage survey has been carried out.

1.5 Terminology

Where the expressions immediate, short term, medium term, long term and very long term are used they generally mean the following:

- Immediate: within 1 year
- Short Term: within the next 1 to 3 years
- Medium Term: within the next 4 to 10 years
- Long Term: within 11 to 20 years
- Very Long term: over 20 years

Where relating to structural damage and crack widths the expressions negligible, very slight, slight, moderate, severe and very severe are used they generally mean the following:

Category 0	"negligible"	< 0.1mm
Category 1	"very slight"	0.1 - 2mm
Category 2	"slight"	>2 but < 5mm
Category 3	"moderate"	>5 but < 15mm
Category 4	"severe"	>15 but < 25mm
Category 5	"very severe"	>25 mm

Table 1. BRE Digest 251

Classification of damage to buildings based on crack widths.

2 Description of Property

XXXXXXXXXXXXXXXXXXX is a right hand semi detached property which appears to be constructed in 25omm wide cavity brickwork beneath a timber pitched and gabled roof with tile covering.

Attached to the right hand side of the property is a single width, single storey garage constructed in 100mm wide ½ brick thick brickwork, with stiffening piers beneath a flat felted roof which slight project forward from the front of the property so forming an attached porch in front of the right side of the main body of the property beneath the flat felted roof.

The drainage was noted to collect around the rear right hand corner of the property and we believe extends out to the front via the right hand side of the building where it connects to the main public sewage system although this cannot be confirmed.

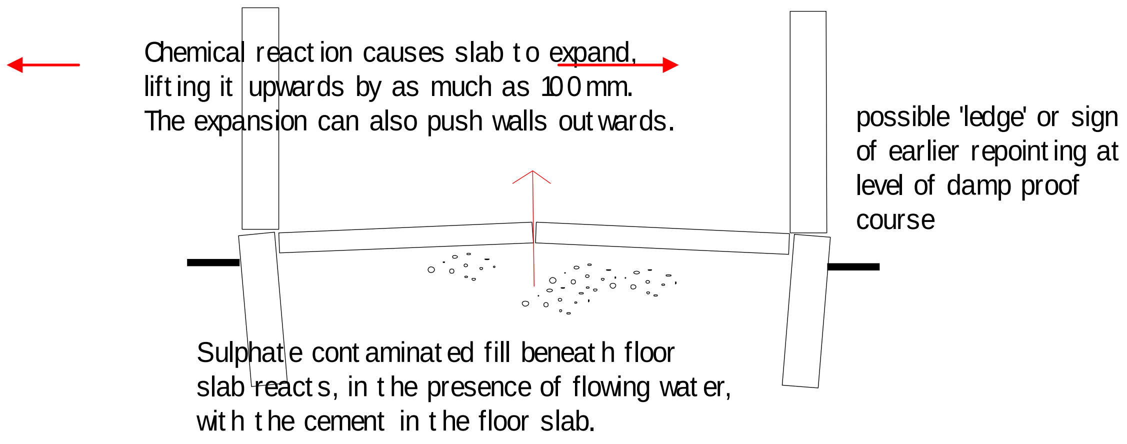
No trees of any significance were noted within influencing distance of the property.

3 Sulphate Attack

Damage to floor slabs indicative of sulphate attack[1] is a commonly encountered problem in houses of this age, style of construction and often found on estates developed in the 1950's and early 60's. More particularly in industrial areas such as those around Birmingham and associated areas.

A timber shortage after the war led to the use of concrete ground floor slabs in place of the more traditional suspended timber floors. Hardcore beneath the slabs was provided from a plentiful supply of clinker (broken brick) from demolished houses, and also furnace ash from industrial processes.

Symptoms include cracking or crazing of the slab, and traces of white salts on the surface. It is not unusual for the upper surface to have a composition or tiled finish. The concrete often has a white appearance, and the slab may bulge upwards towards the centre by as much as 100mm[2].



Typical arrangement of a damaged slab showing the mechanism of failure.

[1] Property Services Agency (1989) *"Defects in Buildings"* H.M.S.O. pp 275. Section 7.1.4
[2] Building Research Establishment (1991) *"Sulphate & Acid Resistance of Concrete in the Ground"* H.M.S.O.

The problem is the result of a chemical reaction between the sulphate contaminated fill on which the floor has been cast, and the cement paste in the slab. Sulphates in solution react with Portland cement to form insoluble calcium sulphate and sulpho-aluminate.

Crystallization of the newly formed compounds is accompanied by an increase in molecular volume of the cement paste between the aggregate[3].

This leads to the slab breaking down gradually, with a consequent loss in strength.

If the containing walls are weak, the slab can actually push them outwards at damp proof course level. Sometimes faint stepped diagonal cracks appear in the external masonry. It is unusual to see any reciprocal damage to the walls internally. These are usually filled when rooms are decorated from time to time.

Although the reaction can also affect the mortar in brickwork, carbonation affords some protection[4], and walls older than 10 years are not usually at significant risk. As an interesting aside, many brick clays are naturally sulphate bearing, and sulphate-resisting cement is needed.

Expansion in mortars has been measured by the B.R.E. who has carried out extensive research. They have detected a 10% increase in volume in aggressive cases, with a 2% increase vertically, and 1% horizontally.

A by-product of the reaction is ettringite, and detection may assist in diagnosis. Unfortunately it is also produced as a consequence of the cement reaction, and specialist advice should be sought from the testing laboratory when interpreting test data.

A constant and replenishing supply of water is required for the reaction to take place. For example, naturally occurring groundwater, water escaping from the drainage system or from a service pipe.

If the supply of water stops, or is diverted, the reaction ceases.

[3] Tomlinson (1984) "*Foundation Design*" Longman Publishing.
[4] Vivian (1961) *"Protection of Mortar from Sulphate Attack"* Australian Journal of Applied Science

The source of sulphates can be: -

- Unhydrated lime or magnesia from steel slags.
- Broken concrete.
- Colliery spoil and gypsum.
- Unburnt coal. Also found as aggregate in the slab itself.
- Oxidised pyrites.
- The clay sub-soil. Many types of clay are sulphate bearing, particularly in the south-east of England. London clays, Keuper Marls, Lower Lias, Oxford and Kimmeridge clays require Class II protection as a minimum.
- Sulphate bearing aggregate.

There are two main types of sulphate attack to concrete.

The first type of attack produces ‘ettringite’ (tri-calcium sulpho-aluminate) and gypsum. For this type of attack to occur the following conditions are required,

- A source of sulphates, generally from sulphates or sulphides within the ground
- The presence of ground water or a source of water (e.g. drain or service pipe)
- Calcium hydroxide and calcium aluminate hydroxide in the concrete mix.

The second type of attack produces thaumasite rather than ettringite in the attacked concrete. For this type of attack to occur the following conditions are required,

- A source of sulphates, generally from sulphates or sulphides in the ground
- The presence of ground water or a source of water (e.g. drain or service pipe)
- Calcium silicate hydrate derived from a cementitious calcium silicate phases in Portland Cement
- The presence of carbonates generally in the course and fine aggregates of the concrete
- Low temperatures (below 15ºC)
- A ph of 10.5 or greater, such as found in the cement paste matrix of non-carbonated concrete.

In the West Midlands domestic floor slabs were very rarely made with a limestone aggregate concrete. It is this aggregate that contains carbonates needed for thaumasite sulphate attack. Therefore when sulphate attack occurs it is almost always of the type that produces ettringite.

Concrete that has suffered from sulphate attack loses its strength and can break down into a friable material. Generally a darkening of the cement matrix with deposits of white crystal occurs which is a visual sign that the attack.

The products formed as a result of the attack takes up more volume than the original products they replace. Ettringite, the crystalline form of calcium sulphate that comprises 3 molecules of calcium sulphate and 31 molecules of water, in particular has a much larger volume that the concrete components from which it is derived. Some of the expansion is taken up within the structure of the concrete floor slab by filling the micropores (very small voids) present within the concrete. As a result sulphate attack can go un-noticed for several years as the expansion of the mix is taken up by the micropores initially. When all the micropores are full the slab will then begin to heave or show signs of lumpiness. Associated with the attack is an increase in the moisture content of the concrete. Some of this increased moisture content is due to the water of crystalline of the ettringite crystal and some is associated with moisture contained in the fractured concrete by capillary action.

As well as the physical symptoms of sulphate attack, the chemical composition of the concrete is measured to determine if excess levels of sulphate salts are present which would be clear evidence of sulphate attack occurring. Sulphate salts measured in concrete can originate from 4 different sources.

- From the cement
- From the aggregates
- From the water used in the mix
- Or from the sulphate attack

In typical concrete used within the West Midlands the aggregates and water used within the mix contain negligible amounts of sulphate.

However cements do contain a proportion of sulphate which can complicate the interpretation of the chemical test results.
The actual rate of sulphate attack depends on several factors

- The type of sulphate salts present
- The sulphate and moisture content of the fill
- The quality and permeability of the concrete
- The level of suction across the slab caused by the height of the dwelling

The rate of attack varies dramatically depending on the above factors. In some dwellings the rate of attack can be very rapid necessitating the replacement of the floor slabs within a few years of them being placed. Many of these properties have already had their floor replaced. Remaining house are the ones that have the attack occurring at a much slower rate and generally have the attack accelerated by an external source such as water suddenly becoming present either through a defective drainage system or leaking water service.

The properties in the West Midland area generally are properties built between the early 1950’s up to the mid 1960’s generally for local authority housing. However properties outside this age have been known to have been effected when they have not been built to the correct Building Regulation guideline in force at the time of construction.

The Building Research Establishment has produced several guides over the years to detail the acceptable levels of sulphate materials adjacent to concrete. Until 2005 BRE Digest 363 (Sulphate and acid resistance of concrete in the ground) was the accepted guidance. In 2005 this was superseded by BRE Special digest 1 (Concrete in Aggressive ground). The guidance has evolved to cater for successive adverse field findings to take advantage of the emergence of new concrete constituents and construction methods and to maintain harmony with newly published standards latterly European ones.

We also refer to BRE digest 363 which was the for runner to BRE SP1 which we believe is more applicable to older concrete floor slabs in aggressive environments that do not relate to modern times. We then compare the results with the current BRE SD1 which we consider is more applicable to the design of new floor slabs in aggressive environments that were not applicable at the time the properties investigated were constructed, such as brown field sites, so as to comply with the current guidelines.

4 General indications of Sulphate attack

Sulphate attack to floors generally occurs when the underside of the concrete slab is exposed to fill materials harmful to concrete such as slag, colliery waste or shale's, which was used in abundance in the late 1950's and 1960's. Concrete to floors in this era also had particularly low cement contents. High cement content concrete has a greater resistance to the sulphate attack.

When a deleterious material has been provided this can attack the concrete in certain conditions and this normally occurs when there is moisture present to act as the catalyst and enables a chemical reaction to take place between the sulphates in the underlying material and the concrete floor.

Superficial evidence of this occurring can be one or more of the following conditions: -

- Heaving upwards of the floor as the concrete expands
- Expansion at Dpc level push the outer brick walls sideways
- Heaving and cracking of the floor
- Moisture able to rise through the top of the floor because of the concrete's reduced strength and density.

Laboratory tests will give an indication of the cement content of the concrete and the sulphate potential of the underlying fill material, which will assist in the identification of the attack.

Ordinary Portland cement contains sulphates, which is added in the form of gypsum during manufacture as without this addition cement would flash set within a few minutes after the addition of water. The amount of sulphate present in cement varies with time and production location, but is usual to assume a sulphate (SO_3) / cement ratio of 3% for normal cements. This value has therefore been used in the calculation of the report results. Present concrete design practice allows for a maximum sulphate (SO_4) / cement ratio of 4% in concrete. This higher value allows for small contributions of sulphate from the concrete aggregates and the water used within the mix.

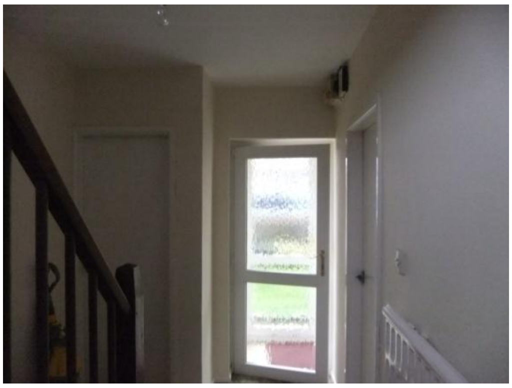
It is also necessary to estimate the dry density of the concrete to calculate the cement content of the concrete tested. A dry density of 2280 kg/m³ has been taken as being the typical for concrete. The same calculation also allows the theoretical cement content of the concrete to be determined on the basis that all of the sulphate found in the concrete is from the cement. As a guide the modern floor slab grade concrete contains between 250 and 300 kg/m³ of cement per cubic metre of concrete.

The tests carried out in investigating floor slabs are designed to allow the results obtained to be compared to the values in the guide. It is widely accepted that for sulphate attack potential to be present the fill material needs to be class DS2 or above. The higher the DS class (DS1 – DS5) the more aggressive the fill will be with respect to the sulphate attack to the concrete.

5 Observations

The floors within the property were generally level with no undue dooming or localised lumpiness which is attributed to the attack having occurred.

No current distortions were noted on internal walls or around door frames to show any heaving of the floor slab.



Externally there was no lateral displacement of brickwork around the damp proof course to consider any lateral pressure exerted from the chemical attack of the slab.

The floor to the left side of the property being the lounge and dining area were suspended timber floors and generally level with no undue dooming of the timber from any sub-floor distortions.

No cracking was noted either externally of internally to the walls.

No lateral spread or white efflorescence was noted externally around the damp proof course which can be an indication that expansion and the attack has occurred.




6 Investigations

A trial hole was excavated through the concrete floor within the pantry area to the front right of the kitchen which was to the rear right corner of the property due to being close to the water source which as a requirement for the attack to occur on the rear right hand side of the property. This revealed that beneath a thermoplastic tile there was a 100mm depth of concrete being of reasonable quality and a greyish colour. Beneath the concrete was a pure black ash being a colliery waste by product No damp proof membrane was present. The ash was directly onto the concrete interface.

Laboratory results

Trial hole location	Material	Moisture Content (%)	Sulphate Content (SO_3)%	Sulphate Content (SO_4)%
Kitchen Pantry	Concrete	6.7	0.6	0.72
	Fill	8.0	1.33	1.60

Concrete Sample

Trial hole location	Cement Content (%)	Cement Content (kg/m³)	Sulphate Cement Ratio for cement Contents of:- (kg/m³)				
			150	200	250	300	350
Kitchen Pantry	10.5	260.4	5.2	3.9	3.1	2.6	2.2

Fill Sample

Trial hole location	Fill Class
Kitchen Pantry	DS 2

B R E Digest 363 Table 1 Classification 2

The samples were analysised in accordance with BRE Special Digest 1 however for ease the previous BRE Digest 363 has also been referred to.

From the above test results it can be seen that the fill material beneath the floor has been classed as Class 2, to BRE Digest 363.

This would require a minimum cement content of 330 kg/m³ to comply with BRE requirements. Testing has shown that the actual cement content is 260.4 kg/m³, which is below the recommended requirement to resist the attack if water was present. The concrete had a grey colour with no indication that the reaction may have commenced.

The fill material was a black vesicular clinker and ash being a colliery waste with no polythene damp proof membrane between the concrete. The concrete had a dry consistency.

In accordance with BRE Special Digest 1 The sub base material falls into exposure category DS-2 similar to the results in BRE Digest 363

7 Conclusions

In conclusion the concrete samples from the trial holes taken in the Kitchen pantry were found to have relative low level of sulphates however the fill material had a high level of sulphates with the cement content of the concrete being lower than that recommended to resist the attack. The concrete was also relatively dry.

We **do not** therefore consider that Sulphate attack has occurred to the property. However this coupled with the classification of the fill material as being an aggressive material in accordance with BRE Special Digest is clear evidence that there is the potential for Sulphate attack to occur to the floors in the future if a drainage leak was to occur or other source of water became present to act as the catalyst.

As there is potential for the reaction to occur in the future if a drainage leak was to occur we therefore of the opinion that consideration should be given to the replacement of the floor slab before the reaction undoubtedly occurs in accordance with current Building regulation guidelines to prevent the chance of the reaction occurring in the future

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END OF REPORT

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