Queries, comments, correspondence, and curiosities . . .

Rubber isolators

Messrs Z Rigbi and J Atlasovitz have written to me from Haifa, Israel, to relate an exercise which provides a useful performance indicator on rubber isolators.

In January 1996, we reported[1] on the design and installation of a series of rubber isolators based on carbon black loaded chloroprene rubber (CR). Each isolator was so designed as to compress between 2 and 2.5mm under the load imposed by the specific column. Over the 19 years that these isolators were in place they behaved well and accepted additional shear strains which were not part of the original specifications.

The engineer for whom these isolators were built was concerned that they might have deteriorated over the years and wished to have a reasonable estimate of their ultimate life. They are actually installed in an ideal ambience – a tunnel free from sunlight or ozone sources and at a fairly constant temperature of approximately 16°C. To satisfy his request, part of the structure was raised by a series of hydraulic jacks and one of the isolators was removed for further study. A substitute isolator of the same design and specification was placed in position and the structure lowered down on it.

The isolator, which had been removed, was taken to a laboratory and the layers separated by means of a reciprocating metal saw, using an oil in water emulsion as a lubricant.

As results show, it was apparent that the CR compound had been slightly softened by the emulsion, presumably both as a result of the absorption of water

Due to the presence of zinc chloride, which is a by-product of the reaction of the zinc oxide curative with the chlorine split off from the rubber, and from the oil taken up by the poly(chloroprene) base itself. The results obtained are given in Table 1.

Although the rubber softened substantially, apparently as a result of the absorption of water and oil in the lubricating medium, its strength has surprisingly increased over the years.

Table 1: Changes in mech props

Mech Prop	Original	Removed from isolator
Hardness Shore A	72	55
Tensile Strength MPa	12.76	17.2
Elongation %	220	395

It can be expected to give many years of additional service. This conclusion is similar to that obtained for isolators in other applications.

1. *The Structural Engineer*, **74/2**, p 29-30, Jan. 1996.

This feedback information is, I suggest, useful to the construction industry. I would be pleased to collate through this column information on retrospective testing of materials

Crack diagnosis

Denis Camilleri, from whom Verulam has received letters in the past, writes from Malta with reference to Roger Johnson's technical note in the Journal of 15 October 2002 and seeks guidance:

An innovative crack classification has been suggested. The three classifications include aesthetic, serviceability and stability, with a decision matrix compiled, depending on whether the crack is static, cyclic or progressive.

However, no allowable crack width values have been inserted into the matrix, which would help towards reaching a decision. Referring to IStructE guide *Subsidence of low-rise buildings* and ICE guide *Has your house got cracks?*, the following guidance is given.

Crack widths below 1mm are definitely aesthetic, but could possibly reach 5mm without affecting serviceability. It appears that if a crack cannot be penetrated by a £1 coin (3mm thick), then it may safely be classified as aesthetic.

Crack widths between 5mm and 15mm would cause serviceability problems, but cracks above 15mm would cause stability problems.

Returning to the decision matrix, if an aesthetic crack becomes progressive, would it still be termed aesthetic? What would be the allowable crack width for an aesthetic progressive crack?

The length for monitoring the cracks was not specified. Should the minimum period relate to the taking of measurements in the summer season followed by the winter season or vice-versa? This should give an indication whether a cyclic, progressive or static movement is occurring, with a preliminary decision taken on whether movement is due to settlement or subsidence amongst other causes.

The table in BRE Digest 251 can be very useful in relating crack widths to degree of damage, but I expect that readers will have their own methods of making assessments of cracks in buildings and formulating the answers to the queries raised by Mr Camilleri.

Reduced pullout forces for highly stressed flanges

Martin Double of Ewell, Surrey corresponded directly with Henry Dalton regarding his letter in this column in the Issue of 1st April 2003 and has kindly forwarded a copy of his letter sent to Mr Dalton which I am pleased to include:

I was interested to read your contribution to Verulam, it's a pity that your whole contribution was not printed as some detail may be misunderstood as a consequence. I would be grateful if you could provide more detail, particularly as this is a hobby-horse of mine.

My own thoughts, on the matter discussed, and associated matters, are as follows.

Some aspects that may cause additional stress, or stress concentration, but are often ignored (or not understood!):

- As you rightly point out the stress due to flange bending will be increased due to direct stress in a member resulting from both axial load and bending.
- Shear stress in the member as a whole, due to global forces, and in the flange, due to local bolt forces, may also reduce the flange bending capacity.
- 'Weak Yield Lines', my own term to describe those yield lines that form long after initial yield has occurred. The question is should these yield lines be allowed to contribute to connection capacity when they may never occur before the structure as a whole is grossly distorted and near collapse? For example, the yield lines in a flange that run parallel to the web are generally the first to develop, whereas those perpendicular to the web may not develop until the initial yield lines have been strained 10-20 times or more beyond yield point.
- An added complication to the last point made, and may be a complication to your own studies, is that yield line patterns extend generally through at least 90° and sometimes to 360°. The 'strong & weak lines' will vary in relation to their angular position. The manner in which global stresses are added to local stresses will therefore vary. i.e. global stresses may be directly added to some local stresses while local stresses that are perpendicular to global stresses will not be added in the same way. Is this considered in your graphs?
- Many of the yield lines in popular use do not appear to be correct in that they are clearly not derived from the equations for 'minimum work done'.

Some aspects that may be beneficial and offset the above (or not) are:

- Local stresses have traditionally been allowed a higher permissible stress (capacity now!) But only if the local stress can redistribute quickly into a larger area of section that will not be stressed more than permissible. A point often forgotten.
- For single-storey buildings the axial loads are generally only about 10% of capacity or less, and bending generally governs member sizing. At the position of the tension bolts, in a moment connection to a single storey building, the column moment is close to zero. Such a connection will therefore not suffer from the effects of stress addition that you describe, but may be

refer to references at end of attached 'No ESCAPE from CDM 13*' for more details.

I would urge all engineers to take the CDM regulations to heart, they are there to protect people's lives and stop us as an industry killing on average two people a week. To this end I hope to see the Institution do more to educate its members regarding their responsibilities under the CDM regulations.

**The attachment contains an extract of the HSE regulations document which for copyright reasons we cannot publish. As reference is made to this text in the attachment it would not make sense to include the rest of the attachment text. We do however attach the references mentioned plus a web site, for those wishing to read further, below.*

- *Website: http://www.hse.gov.uk/pubns/cis41.pdf*
- *Construction (Design and Management) Regulations 19 9 4 SI 1994 No 3140 HMSO 1995 ISBN 0 11 043845 0*
- *Construction (Design and Management) (Amendment) Regulations 2000 SI 2000/2380 Stationery Office 2000 ISBN 0 11 099804 9*
- *Managing health and safety in construction: Construction (Design and Management) Regulations 1994: Approved Code of Practice and guidance HSG224 HSE Books 2001 ISBN 0 7176 2139 1.*

I think the answer to the malaise, if that is what it is, is that CDM is not perceived as engineering* per se *but more of a chore or inconvenience. Nevertheless, even if more paperwork is involved, adherence to the principles of CDM should lead to a healthier set of site safety statistics.

[Ed – Readers can, of course, obtain copies of the regulations mentioned from HSE.]

Front cover of the journal

Clive Shearer has written to me from Washington, USA to say:

In response to Simon Pole's objection to the Journal covers, I add the following thoughts.

Having advertising on the cover does not bother me, although the images can be rather mundane. The warehouse that graces the 17 June cover is a case in point. However, the reality is that:
1. Probably more than 80% of the buildings designed by structural engineers are rather prosaic, so this represents reality.
2. It provides income to a not-for-profit organisation. I do agree that the 'image' of the Institution is not necessarily enhanced by these photos, but then how many architects, contractors, non-structural engineers, and general members of the public see the Journal? Probably very few indeed. So, in short, it matters not. Mr Pole's assertion that only 1 in 4 members peruse the Journal makes me wonder about the source of his statistics. I read with a chuckle his further suggestion that 'too many people are put off from tearing open the shrink wrap by a rather poor first impression'. Mr Pole, please let us know how you get these fascinating tid-bits of information about the habits of the genus '*structuralis engineerus*'. I have no statistics or field observations to back up my belief, but I feel sure that members are able to see beyond a cover. Members who want to read the Journal will read it. Members who choose not to read it will not read it. The cover is incidental.

As a further suggestion to popularise the Journal, why not have a spot, say half a page each month, dedicated to members' photos? One per month. They could be sent in as a print or as a jpeg e-mail attachment. I am sure many members would be delighted to submit their own shots of their latest structure. The Editor might be the judge, and the prize simply the honour of having one's building published without going through the onerous article publication process. Perhaps the best submittal for the year could be voted upon by members with a prize of a tie or other token.

Mr Shearer's idea is a good one, but it is one that IStructE already promotes.

[Ed. Firms that are aware of the value of publicity already send us interesting images of their schemes as press releases which we endeavour to use in our news and p&s pages.]

Crack diagnosis

Roger Johnson of Bristol replies to Denis Camilleri whose letter was published in the Journal of 3 June 2003.

I would like to thank Denis Camilleri for his letter which appeared in the 3 June edition of *The Structural Engineer* regarding the technical note: 'The significance of cracks in low-rise buildings'.

He should appreciate that the technical note is a summary of the half-day course held at the Institution on the subject of 'Crack diagnosis in low-rise buildings'. This course has taken place at the Institution on four occasions and will be repeated in March 2004. It was not possible to include all the material covered in the course in the technical note. To do so would be the equivalent to writing a book!

In any event I will try to answer his questions:

There are number of documents with tables of crack widths relating to repair (not diagnosis). BRE 251 '*Assessment of damage in low-rise buildings*', IStructE '*Subsidence of low-rise buildings*' etc. as well as the ICE guide mentioned in his letter. These documents are mentioned during the course. Whether the crack is significant or not depends on the type of materials, the type of building etc. What is important is to obtain an understanding of how the building is behaving, which is undertaken during the initial inspection and data gathering period. I have personally come across many instances of professionals looking at a crack, measuring its width, referring to a table (BRE 251 for example) and then pronouncing whether the crack is significant or not without assessing whether the crack is affecting serviceability (letting in water, affecting insulating properties etc) or monitoring to check whether the crack width changes are cyclic or progressive.

With regard to the decision matrix, of course if at any point in time an aesthetic crack is found to be progressive, then it is reasonable to conclude that if left unchecked the crack may eventually cause serviceability damage. The important point is that the significance of an aesthetic crack found to be 'progressive' will be treated very differently to an aesthetic crack which is 'static' even though the crack width may be the same when first inspected and measured. A crack is aesthetic if it is not affecting the functioning or the serviceability of the building.

With regard to monitoring period, again, during the initial inspection, a hypothesis on possible causes can be developed and the monitoring will contribute to confirming whether the initial hypothesis is correct. It is not possible to be specific on an appropriate monitoring period for all cases. Each case has to be viewed on its merits. Many cracks are not caused by foundation subsidence or settlement. What is important is to start monitoring as soon as possible, to maximise the time available.

I do hope this has gone some way to answering your comments. If he is able to attend the course in March 2004, then I will be pleased to see him, although I will imagine that this may be difficult if he is living in Malta!

A useful summary from Mr Johnson for those involved in this aspect of the structural engineer's work.

Manual for the design of rc structures

Mr Wickramaratna contacts me from Sri Lanka in relation to a clause in the 2nd edition of the above publication and comments as follows:

I refer to *Manual for the design of reinforced concrete building structures – 2nd Edition*, July 2002.

Section 4.10.5.2 – Axially loaded reinforced pad footings
a) Item No.1 – refers to 'ratio of the overall depth "h" to the projection from the column face "a", given in Table 39' – but table 39 gives d/a, d being effective depth of base.
b) Again in Item No.1 – 'effective depth "d" should not in any case be less than 300mm – but the earlier version of the manual refers to "h" not less than 300mm.
c) The steel percentages given in table 39, is it related to 'd' or 'h'?

Please could you verify?

With only a copy of the 1st edition to hand, I would say that the reference to 'h' being not less than 300mm should read 'd' not less than 300mm in order to provide sufficient depth for the column bar anchorage length. It is usual to write depth ratios in terms of the effective depth but steel reinforcement percentages are usually written in terms of the overall depth. If I am wrong in this instance I shall pass on the correct version in a future issue.

Emails can be sent to Verulam via: reynolds@istructe.org.uk

Letters should be kept as short as possible, and preferably clearly typed. Illustrations cannot be redrawn: please ensure they are suitable for publication.

The significance of cracks in low-rise buildings

Roger W. Johnson distils some of the wisdom from his workshop on crack diagnosis held at the IStructE

'Is that crack serious?', asks the owner of a house a day before they are due to exchange contracts on the sale! This is one of the simplest questions to ask, but for the structural engineer one of the most difficult to answer – at least within the timescale demanded by some property owners.

Most buildings crack at some time during their service life. The appearance of cracks is a symptom of distress within the fabric of the building. Often the cracking is of little consequence and once it is established as static, simple repair by filling or re-pointing is all that is required. However a crack maybe the first sign of a serious defect which may affect the serviceability or the stability of the building.

Fig 1. Is that crack serious?

Fig 2. This crack has probably been filled before, with cement mortar. The wall appears to be random stone wall laid originally in lime mortar. The repairs to part of it with cement mortar can alter the manner in which it behaves

The appearance of cracks can also affect the value of the building – whether it can be insured or sold, or be the subject of litigation. Therefore correctly assessing the significance of cracks is essential. However it is a far from a simple task and is often a subjective exercise. The implications of an incorrect assessment can lead to expensive and unnecessary remedial work. In some instances the remedial work may exacerbate the problem resulting in yet further and more extensive cracking.

–So how does the professional adviser decide if the cracks are significant? Professor Malcolm Hollis once stated: 'Surveying buildings is an art, verifying the cause of failure is a science'[1].

It is therefore important to develop a methodology or systematic approach so that any action taken is appropriate to the cause. The following methodology should not be followed rigidly because each case will differ on its merits, but it provides a systematic method of gathering information and then assessing the significance of cracks.

The initial inspection

During the initial inspection do not give opinions under pressure from the client. If you speak at all confine your comments to asking questions as part of the data gathering exercise. Do not just stand and stare at the cracks – they are unable to speak and will not give you any clue as to their cause. Instead stand back, look at the whole building from a distance. Walk round it. Look at the condition of adjoining buildings and other features such as trees. Always work from the general to the particular.

Structural alterations to the building should be identified or any alterations that may have affected its structural integrity. Note its age, if it has been extended, or if part has been demolished. Always be suspicious of how a building is constructed. Recent decorations may conceal existing cracks.

The pattern of the cracks should be studied. Cracks in masonry generally manifest perpendicular to the line of force[2] although this can be distorted by the relative stiffness of the building elements. Cracks will tend to follow lines of weakness, e.g. cracks in a wall panel will usually occur between door and window openings which are the areas of weakness in a wall panel.

The construction materials should be noted. The age of the cracks should be determined if possible. The building owner or occupier may be able to provide useful information. The edges of old cracks are often weathered and the crack filled with debris and cobwebs. Some cracks are of uniform width, others taper. The direction of the taper should be noted. Cracks caused by shear forces tend to leave lumps of debris attached to one side of the crack. Occasionally cracks will occur due to compression.

At this preliminary stage it may be possible to develop a hypothesis to identify a link between the symptom and cause of cracking. There will usually be insufficient information to fully diagnose the cause of cracking at this stage of the investigation, so develop a conceptual model based on the information gathered to date. This will help you to decide how the building

Fig 3. The foundation is subsiding due to action of the tree roots. The line of force is diagonal and the cracks are appearing perpendicular to the line of force. The cracks follow the line of weakness, in this case the window openings

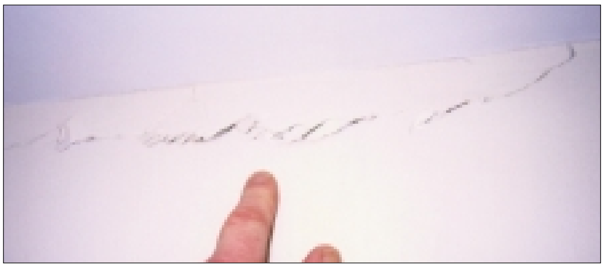

Fig 4. (above) Crack caused by shear

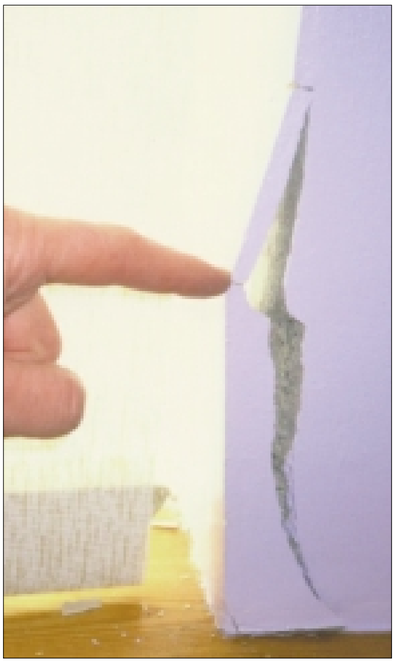

Fig 5. (left) Crack caused by compression

is behaving and assist you in developing the systematic strategy for moving the investigation forward. The strategy is an iterative process that is reviewed and amended throughout the investigation.

In this example the cracks are wider at the top of the elevation than the bottom, suggesting that maybe the foundations to the two gable ends are experiencing settlement or subsidence, or perhaps the centre of the building is lifting due to heave. This observation is not conclusive but it can help with deciding on the next stage of the investigation.

Fig 6. (below) A conceptual model

The crack survey

The next stage is to undertake a present condition survey of the cracks. The crack widths are measured and the characteristics of each crack are plotted onto a drawing or sketch of the building. The characteristics to be recorded are width, direction, taper, frequency and location. If it is possible it will be useful to differentiate between cracks caused by tension, compression and shear stress. A crack on the opposite side of the wall can be shown as a broken line. Standing back from the building and plotting the cracks can help with identifying the overall pattern of movement and developing the conceptual model.

Crack monitoring

Crack monitoring should be started as soon as possible. The longer the crack monitoring period, the more data will be available for diagnosing the cause. The monitoring should continue throughout the data gathering, the investigation and the remedial work. It should continue beyond the completion of the remedial work in order to validate the performance of the remedial measures.

Monitoring changes in crack width is important as the following case shows. A local authority approved a foundation design which later was found to be inadequate. A structural engineer recommended underpinning the foundations. The local authority was sued for the cost of the underpinning. However the local authority was held not liable because the structural engineer had recommended underpinning without monitoring to establish if the movement was progressive. (Bluett and Another *v.* Woodspring District Council 1982).

Fig 8. (above) Plot the cracks onto a drawing and note the crack widths in mm. The arrows indicate increase in widths of cracks

Crack monitoring methods

The next step is to decide the type of crack monitoring equipment to use. Proprietary gauges, using the generic name 'Tell-Tales' are an inexpensive, easy to install method of crack monitoring. Always make sure you use a tried and tested type manufactured to ISO 9002. You are placing great reliance on the readings and you may be liable if you recommend unnecessary remedial work on the results of unreliable products. They are accurate to a resolution of 1.0mm and by interpolation to 0.5mm. They can record horizontal opening and closing of the crack as well as vertical shear movements. They are ideal for plotting the trends and direction of movement and verifying the adequacy of remedial work.

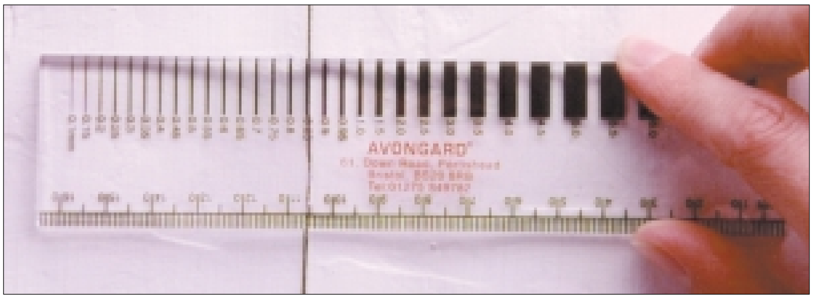

Fig 7. (right) It is quicker and easier to use a proprietary crack width gauge to measure the crack widths

Cracks commonly occur in corners at the junction of walls. Use the type of gauge that is hinged. Most corners are not built precisely to 90° and this type will fit snugly into a corner of any angle, even a bay window corner of 45°. If the gauges are used in pairs and 'handed', movement in three dimensions can be monitored.

Precision calipers are used for more accurate monitoring. A vernier, dial or digital caliper can achieve an accuracy of 0.1mm if used by an experienced operator. The distance between two datum points fixed either side of the crack is measured with the jaws of the caliper. Three datum points can be used for the monitoring of vertical movements across the crack. The datum points are 6mm stainless steel discs with a hole drilled in the centre into which the jaws of the caliper are placed.

The following factors need to be considered when selecting the appropriate crack monitoring system:

- *The sensitivity of the location needs to be considered*. Will Tell-Tales draw unwelcome attention to the cracks in the building? In which case will unobtrusive stainless steel discs be more appropriate? Will the presence of Tell-Tales provide comfort and re-assurance to the building owner that no movement of the crack is occurring?
- *Who is going to take the readings?* Is

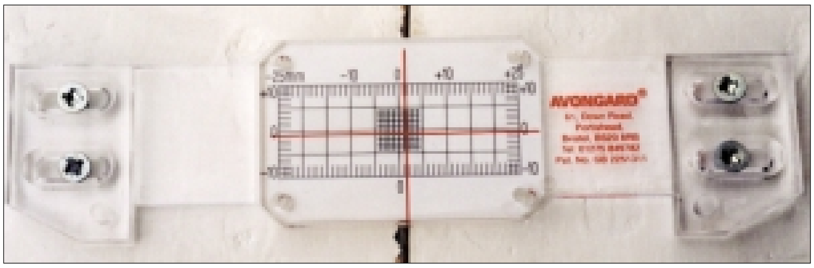

Fig 9.
Use the type of gauge which has the facility to 'upgrade' the resolution of the readings to 0.1mm with precision calipers. This will give you the option to speed up the monitoring period if you are trying to identify trends of movement across the crack

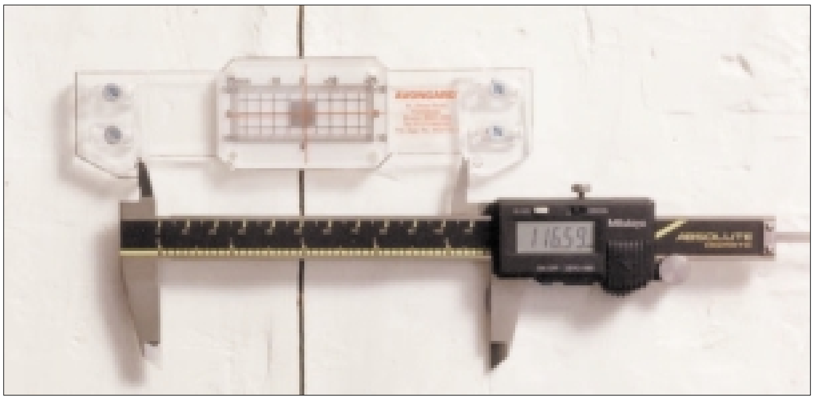

Fig 10.
Upgrading the resolution with precision calipers

the building owner going to record the movements with the results sent to the professional for analysis during the monitoring period? In which case Tell-Tales are much easier to read.

- *What is the required resolution?* Is 1.0mm sufficiently accurate or is a finer resolution required?

Gathering data

Throughout the crack monitoring period further information should be gathered. This may include the following:

- *The history of the site*: examining aerial photographs and reviewing old maps, archive material and local authority records.
- *The geology of the site*: studying geological maps and memoirs.
- *Further inspection of the site:* noting signboards, examining open trenches, vegetation, adjacent buildings and features on adjoining land. Lifting drainage manhole covers to inspect whether drains are leaking.

If the cracking appears to be the result of foundation subsidence or settlement, trial pits should be excavated to expose the foundation and supporting soils for inspection and soil samples taken for testing. In addition boreholes should be sunk and plumb and level surveys[3] undertaken. If chemical reaction appears to be the cause, samples of material for laboratory testing should be taken.

Common causes of cracking

The majority of low-rise buildings in the UK are constructed using brick, concrete block or stone with mortar joints. These materials possess significant compressive strength but their ability to accommodate tension is limited. As a consequence if tension stress develops cracking frequently occurs. There are numerous possible causes of cracking. There may be a single cause or a combination of several causes, or one primary cause with several contributory factors. It is beyond the scope of this article to list more than just a few:

- foundation subsidence or settlement
- incompatibility of building materials
- chemical reaction of materials
- thermal movements
- changes in moisture content
- structural instability.

There are many published documents describing in more detail the various causes of cracking in low-rise buildings[2,4,5].

The objective of the initial inspection, the crack survey and monitoring and gathering data is to enable you to collect sufficient evidence to support an objective opinion on the significance of the cracking.

Is the cracking significant?

The client has asked the question: 'Is that crack serious?' In the midst of the collecting evidence it is an easy matter to lose sight of the original concern of the client. The results of the initial inspection, the crack survey, crack monitoring and gathering data should answer the following questions:

- *Is the movement across the crack static?* This can point to the following possible causes:
  - the initial 'bedding in' of foundations of a new building;
  - Initial shrinkage of construction materials;
  - load induced deflection of beams and slabs as a result of imposed dead load.
- *Is the movement across the crack cyclic?* This can point to the following possible causes:
  - thermal movement;
  - seasonal clay shrinkage and swelling affecting shallow foundations;
  - the formation of ice lenses in certain soils causing the effects of expansion and shrinkage on shallow foundations.
- *Is the movement across the crack progressive?* This can point to the following possible causes:
  - roof spread of a pitched roof;
  - foundation subsidence and/or settlement due to: leaking drains, filled ground, or peat and compressi-

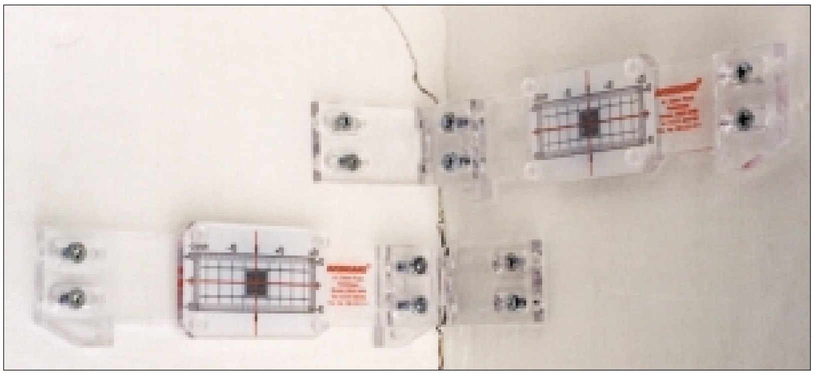

Fig 11.
Monitoring cracks in corners

Fig 12.
Monitoring with a digital caliper

Fig 13. (left) This crack is aesthetic damage only

ble soils;
- clay shrinkage and swelling caused by trees;
- hillside creep and instability;
- chemical reaction: sulphate attack, carbonation or alkali silica reaction.
- wall tie corrosion.

The cracks can be classified into three categories discussed below.

- *Is the crack only aesthetic?* Some cracks only affect the aesthetic appearance of the building and do not affect the functioning or the building nor do the cracks cause structural instability.
- *Is the crack affecting the serviceability?* If the cracking affects the functioning of the building or individual elements the damage is described as serviceability damage. For example, the building is no longer watertight, the functioning of the drains and the services are impeded, the glazing in the windows breaks or the doors do not open or close.
- *Is the cracking affecting the stability?* It is rare for a building or structure to suffer sufficient damage for it to affect the overall stability, but if movement is allowed to continue unchecked, individual elements may become unstable, e.g. the reduced bearing of a beam due to differential movement at its support.

In order to focus your mind on assessing the significance of the cracks, the decision matrix is a methodology that may be applied[6], ticking the appropriate box in the matrix for the combination of factors that are appropriate to the cracking. For example, if the cracking is found to be only aesthetic and static, the remedial work is usually simple and inexpensive and there is no need for further monitoring. However remedial work becomes potentially more complex and expensive if the cracking is found as a result of the monitoring to aesthetic and progressive, because the movement may progress from only aesthetic damage to affecting serviceability and ultimately the stability of the building.

Fig 14. (left) The crack width adjacent to the window frame is about 60mm. Clearly the building is no longer watertight and the thermal insulation is being compromised. In time the construction materials will degrade

Decision matrix

	Static	Cyclic	Progressive
Aesthetic			
Serviceability			
Stability			

This methodology will not eliminate the need through analysis and investigation to identify the cause or causes of cracking and specify appropriate remedial work. However if it is applied it will result in a more rational and consistent approach to the assessment of cracking in buildings. Its application will result in recommendations that reflect the severity of the cracking, the need for urgent remedial work or whether further monitoring is required.

This article is an extract from the material used in a full- or half-day interactive workshop organised by Avongard on 'Crack diagnosis in low-rise buildings. Roger W. Johnson is the former Chief Engineer to the National House Building Council, a Consultant to Parkman plc and the Technical Director of Avongard Ltd (web: www.avongard.co.uk).

Fig 15. (right) The panel of wall on the left of the crack is leaning outwards. There is only minimal lateral restraint at the gable and first floor. This section of wall could be categorised as unstable

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