Cracks and How Damaging are They?

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Abstract

This paper presents a brief review of various types of cracks and their probable causes. The likely places and situations where they can occur are highlighted. Simple methods of identifying cracks through crack widths and patterns are illustrated. The usual questions are "How detrimental are these cracks? "and "Do I need to do anything about them?"

INTRODUCTION

As engineers we are often asked to investigate cracks that appear in buildings. People are anxious to know whether the cracks are serious. *(Figure 1: courtesy of and permission by Shaiky)* The recent spate of publicity on cracks appearing in houses, buildings and even on highway structures certainly does not give much confidence to the public.

It may be alarming to the layman that most buildings crack at some time in its service life. Basically concrete has low tensile strength and any induced tensile stress may cause the concrete to crack. The most common type of crack is that caused by the shrinkage of concrete.

Reinforced concrete by nature will crack [1] and for normal structures the aim is to minimise cracking. However, with the construction of water-retaining structures and marine structures the criteria may be quite different and the limits more stringent. One of the best methods to prevent cracking is by using prestressed concrete. Wall panels have been cast with light prestressing to prevent cracks. Prestressed concrete is commonly used in marine structures.

What is the allowable or acceptable crack width? Like allowable settlement, the allowable crack size depends on the usage of the building and its function. Sometimes large cracks in factories or warehouses are tolerated or not noticeable whereas even slight cracks in residential buildings are objectionable. Cracks in walkways are generally ignored by the public. However, the presence of cracks may be a tell-tale sign of structural failure.

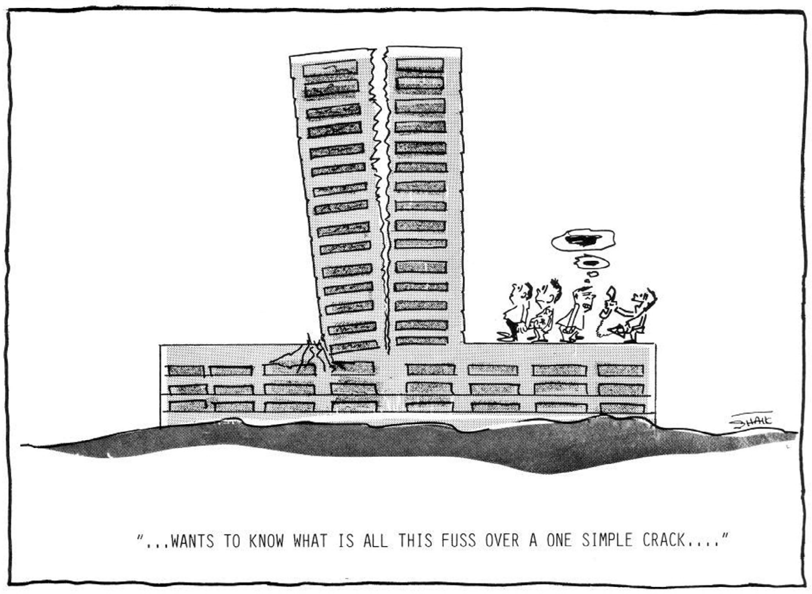

Figure 1: How serious is the crack? (Courtesy of and permission by Shaiky)

There are two main categories of cracks: non-structural and structural. Obviously not all cracks threaten the structural stability of buildings. Non-structural cracks may pose aesthetic problems and, in exposed situations, perhaps allow water to leak through putting the reinforcement at risk of corrosion besides the obvious and immediate problem of water infiltration. They may cause further deterioration if left unchecked. Structural cracks can be very damaging and millions of ringgit have to be spent on repairing structural defects.

NON-STRUCTURAL CRACKS

As mentioned earlier, non-structural cracks are cracks that do not jeopardise the stability of the structures.

Non-structural cracks are usually caused by the following:

1. Poor concrete mix
2. Poor workmanship and construction methods
3. Improper or no construction joints
4. Poor structural detailing

Neville [7] gives a comprehensive listing of different types of non-structural cracks. Some examples are as follows:

1. Drying shrinkage cracks

Drying shrinkage cracks are the most common of the non-structural cracks. We have often heard the phase "Don't worry, they're only shrinkage cracks". Shrinkage cracks can occur in wet and hardened concrete. Almost all mixes contain more water than is required for full cement hydration. On drying out, the loss of this excess water is taken up by pores as well as shrinkage. The reduction in volume when restricted, which is often the case in most construction, may cause the concrete to crack. (Figure 2) The usual causes of shrinkage cracking are mixes with high water/cement ratios, inadequate curing and no provision of construction joints. Light weight concrete has a higher tendency to crack compared to normal concrete [7].

Figure 2: Typical shrinkage cracks in floor slabs

2. Plastic shrinkage cracks

As the name suggests, these cracks appear when the concrete is still plastic (wet). These cracks can happen even before the concrete attains any significant strength. Plastic shrinkage cracks normally occur in high water mixes. Rapid evaporation of the excess water normally due to high air temperature, low humidity and strong wind is the main cause of this. Plastic cracks can be widespread especially in concreting large slabs in very hot weather when no proper curing and protection against the heat and wind are provided. (Figure 3)

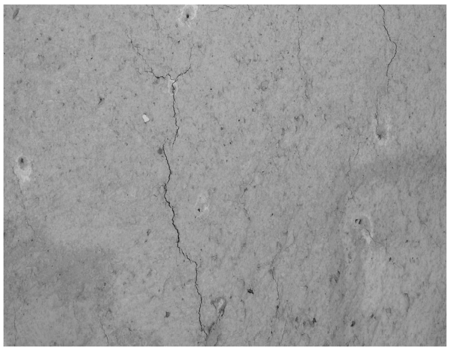

Figure 3: Plastic shrinkage cracks caused by rapid evaporation of water

3. Thermal shrinkage cracks

The hydration of cement causes heat to be generated and as the concrete cools, shrinkage will happen as a result of thermal contraction. When casting large or thick sections such as raft foundations, the amount of heat generated can be huge. For this reason most large pours should be cast at night.

4. Crazing cracks

These are fine cracks which appear on the surface of the concrete in hexagonal patterns or irregular network (Figure 4). Crazing cracks may be caused by excessive floating and trowelling which will bring water to the surface producing a weak skin which will crack. Another cause of crazing is rapid evaporation of water from the surface during the early stages of hydration of overly wet concrete and the lack of curing. These cracks are not damaging but are aesthetically unpleasant.

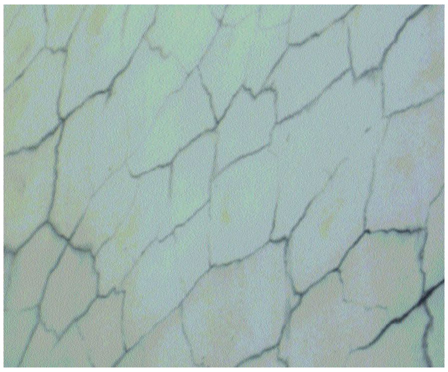

Figure 4: Typical crazing cracks

STRUCTURAL CRACKS

Structural cracks are of serious concern as they can affect the stability of buildings and damage can be substantial. Structural cracks must be evaluated immediately and, if necessary, a monitoring regime implemented.

Structural cracks are usually caused by the following:

1. The settlement of the foundation
2. Deformation of the structure due to overloading or design deficiency
3. Poor construction methods / Errors in construction
4. The movement of the ground such as ground upheaval and landslide.

Cracks arising from upheaval and lateral forces are much more devastating than those due to settlement and quite often buildings have to be demolished.

Figure 5: Cracks in walkways due to no proper construction joints

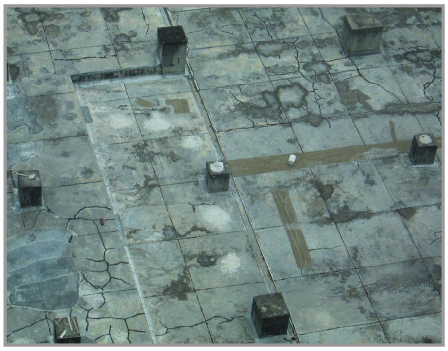

Figure 6: Cracks in flat reinforced concrete roof

COMMON AREAS WHERE CRACKS MAY APPEAR

Flatwork and suspended slabs

Slabs are prone to non-structural cracks or shrinkage cracks because of their large exposed areas and the difficulty in protecting against rapid drying. Beams and columns are shielded from adverse environmental conditions by formwork. Another reason is that slabs are lightly reinforced and usually do not have top steel throughout. In concreting works, especially in large slabs, it is vital to have construction joints to prevent cracking. Figure 5 shows cracks in flatwork (or slab on ground) where no proper construction joints were provided. Interestingly, these large cracks never seem to cause any concern to the public, as noted by the author.

Reinforced concrete roof slabs

A flat reinforced concrete slab is a useful design for roofs as it provides storage space for water tanks, air-conditioning equipment and even space for roof gardens. However of late, reinforced concrete flat roofs have been avoided by local engineers because of the problem of water leakage. A classic example of cracking of reinforced concrete flat roof is given in Figure 6. The column stumps appearing from the slabs are for future addition of extra floors. As the slab might have been designed for floor service, cracks will definitely appear. The reinforced concrete roof, if designed and constructed correctly, can be leak-free.

Car parks

One of the most common places to find cracks is underground car parks (Figure 7). Most basement car parks are constructed using the flat slab technique. Cracks may be caused by poor design of construction joints and failure to take dynamic loading (traffic) into account.

Figure 7: One of the most common places to find cracks is underground car parks

Figure 8: Service conduit in beam can cause cracking if located in the critical part of the structural member

Figure 9: Cracking of brickwall extension because of differential settlement

Service conduits in structural members

When service ducts are required to penetrate through structural members, the approval of the consulting engineer must be obtained. Service conduits are often positioned in the wrong part of structural members (Figure 8). The structural engineer will know the critical areas of shear force and bending moments and can advise the contractor accordingly.

Incompatibility of building materials

When buildings are constructed with different materials, cracks may appear if the connection between the two is not treated correctly. An example of this is at the timber window and door frame areas.

Building in landfills

Landfills contain loose waste and organic matters which are highly compressible. Building in landfills has always been prone to settlement cracks because of consolidation of the ground.

Dewatering of ponds

Uncontrolled dewatering has always been problematic in construction. Many buildings and houses have been damaged due to large settlement caused by dewatering. This is particularly critical if the structures are built on soft ground. In Malaysia most of the problems associated with dewatering occur in former mining pool areas.

House renovation or extension

The norm in Malaysian housing is for new houses to be renovated before the owners move in. The most common is extension of the kitchen and the new extensions are usually built on pad or striping footings irrespective of whether the building is founded on piles or not. Cracks will appear especially if it is built on poor ground. Figure 9 shows settlement of a brick wall extension in marine ground

Construction of new foundations and deep excavations

When pilings and deep basement excavations are carried out near existing buildings, cracks may appear due to ground movement.

SOME PROBLEMS ASSOCIATED WITH CRACKS

Corrosion of reinforcement

The presence of cracks may allow water to infiltrate into the reinforcement causing corrosion and eventually spalling of the concrete. This is particularly serious in marine structures. Figure 10 shows severe corrosion of the steel and immediate repair work is required.

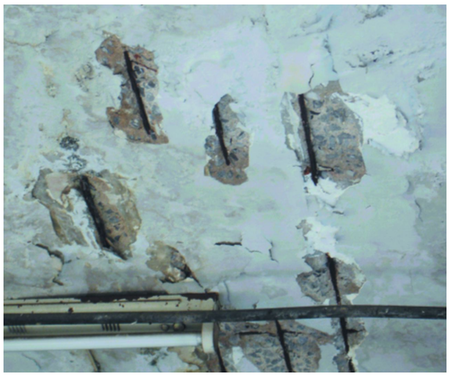

Figure 10: Corrosion of reinforcement can be a huge problem in marine structures

Figure 11: No, this's not a limestone hill but a classical example of efflorescence

Efflorescence

One problem that can arise from cracks is efflorescence which is the depositing of whitish crystalline salt on the surface of the concrete. When water percolates through the crack, it will dissolve salts in the form of calcium hydroxide. The calcium hydroxide reacts with the atmospheric carbon dioxide and on evaporation will form calcium carbonate.

$(Ca(OH)_2 + CO_2 = CaCO_3 + H_2O)$

A classic example of carbonation is shown in Figure 11; the formation of calcium carbonate resembles that of stalactites in limestone hills. Normally efflorescence has no critical effect on the building but it is unsightly and if left unattended may lead to corrosion of the reinforcement.

Property Valuation

The value of the property may be affected by the presence of cracks. Repair works often don't look the same as the original unless the budget allows for re-plastering and re-painting.

HOW TO EVALUATE THE SEVERITY OF CRACKS?

Identification of a crack is not as simple as it seems. A crack which looks non-structural may turn out to be otherwise. Progressive cracks usually indicate more serious problems. However, some cracks are obviously serious judging from the visual appearance (Figure 12). The initial assessment of the crack is through visual inspection, namely the size and pattern of the cracks.

Figure 12: There is no need to evaluate this crack, its serious damage!

Table 2: Tolerable crack widths
REINFORCED CONCRETE (ACI 224R-90)

EXPOSURE WIDTH	TOLERABLE CRACK CONDITION (inch)	(mm)
Dry air protective membrane	0.016	0.40
Humidity, moist air, soil	0.012	0.30
Deicing chemicals	0.007	0.18
Seawater and seawater spray; Wetting and drying	0.006	0.15
Water retaining structures	0.004	0.10

Table 1: Classification of Visual Damage to walls (Burland and Day)

Damage Category	Description of typical damage width	Approximate crack width (mm)
1. Negligible	Hairline cracks	< 0.1
2. Very slight	Very slight damage includes fine cracks that can be easily treated during normal decoration, perhaps an isolated slight fracture in building, and cracks in external brickwork visible on close inspection.	1
3. Slight	Slight damage includes cracks that can be easily filled and redecoration would probably be required; several slight fractures may appear showing on the inside of the building; cracks that are visible externally and some repointing may be required; and doors and windows may stick.	3
4. Moderate	Moderate damage includes cracks that require some opening up and can be patched by a mason; recurrent cracks that can be masked by suitable linings; repointing of external brickwork and possibly a small amount of brickwork replacement may be required; doors and windows stick; service pipes may fracture; and weathertightness is often impaired.	5 to 15 or a number of cracks >3
5. Severe	Severe damage includes large cracks requiring extensive repair work involving breaking out and replacing sections of walls (especially over doors and windows); distorted floors; leaning or bulging walls; some loss of bearing in beams; and disrupted service pipes.	15 to 25 but also depends on number of cracks
6. Very severe	Very severe damage often requires a major repair job involving partial or complete rebuilding; beams lose bearings, walls lean and require shoring; windows are broken with distortion; and there is danger of structural instability.	Usually >25 but also depends on number of cracks

1. Crack width

The size and, to a certain extent, the number of cracks are the main criteria for evaluating the seriousness of cracks. Table 1 gives a good guide to the classification of visible damage with regard to the size and number of cracks. However, consideration should also be given to the location of the cracks. Categories 1 to 3 are normally not critical, while categories "Severe" and "Very severe" should be given serious and immediate attention. Table 1 may not be applicable to water-retaining structures and buildings in marine conditions where even minor cracks are not acceptable.

The American Concrete Institute published a guide ACI 224R-90 to tolerable crack widths for various exposure conditions for durability design (Table 2). Note that this guide applies to the tensile face of reinforced concrete structures.

2. Crack patterns

Non-structural cracks are normally short and irregular and usually do not reach the ends of the walls. Structural cracks are distinct and continuous starting from the end of the walls. Structural cracks are usually also diagonal in direction. The

Figure 13: Common shrinkage cracks at window areas

Figure 14: Structural cracks due to differential settlement

Figure 15: Cracks which are moving or progressing cannot be repaired with cementitious mortar

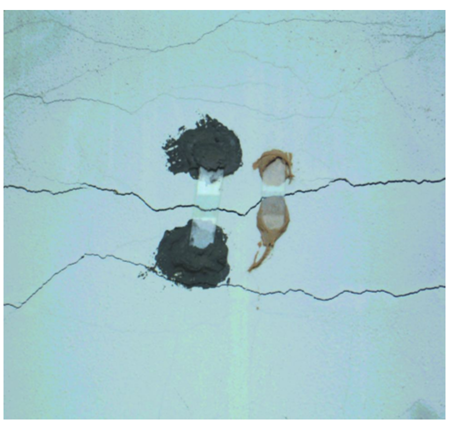

Figure 16: The traditional method of monitoring cracks by gluing a piece of glass across the crack using a rigid adhesive

difference between non-structural and structural cracks is illustrated in Figures 13 and 14. Both cracks are located in the window areas.

Monitoring of cracks

It is important to investigate if the cracks are progressing and widening or arrested. Repair works should start only

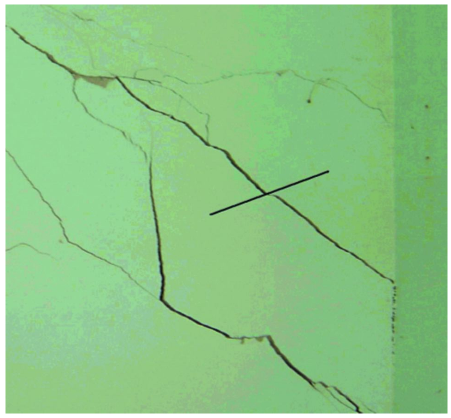

Figure 17: Crack can also be monitored by rawing a straight line across the crack

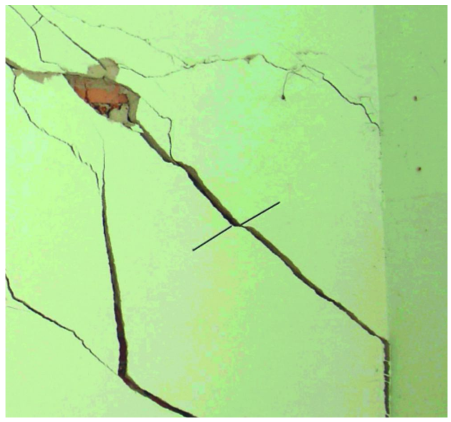

Figure 18: The line which was originally straight is now out of alignment indicating the crack has widened

after the distress e.g. settlement has stopped. There is no point in repairing the cracks if the cause is not addressed (Figure 15).

The most common method to see if the crack is widening is by gluing a piece of glass across the crack using a rigid adhesive. Any further movement will break the glass (Figure 16).

A simpler and cheaper way is to draw a straight line with a thick marker pen across the crack (Figure 17).The line will not be straight if the crack is progressive as shown in Figure 18. Robert Day (ref 4) gives a simple method of measuring the width of the crack by simply installing crack pins across the crack and any widening can be deduced by measuring the pins.

SO WHY DO CRACKS OCCUR?

1. Improper structural and foundation design.

Settlement of the foundation is the main cause of structural cracks. Settlements are often due to either poor foundation design or construction. Cracks can also be caused by over-loading or under-design of structures. Poor structural detailing is another cause of cracking.

2. Improper mix design.

Too much water in the concrete mix promotes shrinkage cracks. Higher cement contents also increases the tendency of cracking because of greater hydration temperatures. In water retaining codes (e.g. BS5337:1976) maximum cement contents are clearly specified. This is in contradiction with the design for durability where minimum cement content is often stated. The main goal for non-crack concrete is low water/cement ratio provided good workability is achieved through the use of admixtures.

3. Improper construction methods.

Contractors and supervising parties should be knowledgeable and persuaded in good concreting methods. Water should never be added to the mixer truck at site to recover lost slump. Water should also not be added to the placed concrete to aid finishing. What has happened to the good old method of curing like moist gunny sacks as shown in Figure 19? Curing seems to be largely ignored in the local construction industry. Concrete should be placed in the minimum time, well-vibrated and cured. Concrete should also be covered as soon as it has been placed and sheltered from the sun and wind.

Incorrect placing of slabs reinforcement is another problem. Construction workers often bind the top and bottom steel of slabs for ease of construction.

Figure 19: Curing of slabs with moist gunny sacks

4. Improper construction joints

Faulty construction joints (or worst still, no construction joints) are a recipe for cracks. The question of whether the structural engineer should provide construction joint details to the contractor is debatable. However, for water retaining structures and reinforced concrete retaining walls, the construction joints (and joint treatments) are always detailed in the engineer's drawings.

5. Improper materials

Some aggregates will react with cement to cause alkali-aggregate reaction. Admixtures containing calcium chloride may lead to corrosion of the reinforcement. Low quality bricks absorb more water and cause cracks in the plaster.

CONCLUSION

Cracks of whatever size are not tolerated by house owners. Fortunately most cracks are not damaging and can be easily repaired.

Cracks are divided into two types: non-structural and structural. Non-structural cracks are usually not critical, but may be unsightly in appearance. However in marine and water-retaining structures, cracks may lead to accelerated deterioration of the structures.

Structural cracks are of serious concern and should be assessed, monitored, and repaired by professionals. As repair works can be expensive and disruptive, prevention of cracks is the key consideration.

The Engineer has to take the lead in the prevention of cracks. Design engineers should be familiar with the fundamentals of concrete technology and construction methods and contractors should be constantly reminded (and supervised) of the principles of good concreting.

Cracks can be minimised by good engineering design and detailing and good construction practice. It is generally recognised that prestressed concrete is most suitable in preventing cracking and is normally used in marine structures.

Initial assessment of cracks is by visual inspection of crack widths and pattern. If it looks bad, have it inspected and assessed by a qualified and experienced engineer. ■

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