IEM Technical Division: Civil & Structural Engineering

CPD event: Tuesday 7th August 2018

Non-Structural Cracking in Concrete:
What codes of practice don't (cannot) tell you!

by

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Welcome!

Thank YOU for attending

Special thanks to the Chairman of the Civil and Structural Engineering Technical Division (CSETD):

Ir. CHONG CHEE MENG

Warning!

I'm going to try to be provocative (deliberately!)

I apologise, in advance, if I upset, frustrate or anger anyone!

My aim is to get you thinking and to reflect on what you do.

(The UK has similar challenges to those in Malaysia! You are not alone!)

Introduction: Steve Garrity

41 YEARS SINCE GRADUATION (AND COUNTING)!

BSc(Hons), MSc, PhD, CEng, CBuildE, MICE, FIStructE, FCIHT, FCABE, FIMS

Approx. 40% of career spent in public & private sector industry

Site engineer, civil engineering contractor, UK;

Graduate Engineer with Sir Alexander Gibb & Partners, Consulting Civil Engineers, UK;

Bridge Engineer, Greater Manchester County Council, UK;

Principal, Garrity Associates, consulting civil & structural engineers, UK

Approx. 60% in academic environment

University of Bolton

University of Bradford

Head of Civil & Environmental Engineering (1997 – 2002);

Visiting Professor in Civil Engineering Design (2007 – 2010);

University of Leeds

SINCE 2009: (FULL) PROFESSOR OF ARCHITECTURAL ENGINEERING

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Part 1:
Setting the Scene

Some initial questions 1

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1. How many of you are involved (regularly) in the **design or specification** of concrete construction (plain, reinforced or prestressed)?

2. How many of you work for contractors or sub-contractors (e.g. Pre-cast concrete manufacturers) and are involved (regularly) in **construction** with concrete?

3. How many of you work for client organisations and are involved (regularly) in the **supervision or approval of concrete design work or construction**?

4. How many of you think that it is important to understand why concrete cracks and what can be done to minimise cracking?

5. How many of you were taught much about cracking in concrete when you were at University (or College)?

6. Since you left University (or College), how many of you have had (or sought) any training that relates to the control of cracking in concrete?

Some initial questions 2

7. Whose responsibility is it to control or minimise the risk of cracking? Is it:

a). The **Client** (or their specialist engineering representative)?

b). The **Designer** (or Specifier)?

c). The **Contractor** (or sub-contractor/supplier)?

Answer?

EVERYONE has a role to play in controlling cracking!

(OF COURSE!)

Concrete & Cracking – the basics 1

WHAT WE ALL KNOW ………..

a). Concrete has a relatively large compressive strength but a much lower tensile strength

b). *It is a brittle material with very little ductility*

c). To overcome these 2 main limitations we usually reinforce concrete with a **ductile**, **high tensile strength** material which has a **similar coefficient of thermal expansion** – **CARBON STEEL** *(alternatively we prestress it to overcome any tensile stresses)*

d). *If we can protect the steel against the effects of fire and corrosion and protect the concrete from chemical attack it can be very successful*

e). The compressive strength of concrete is important - we use it in our specifications (and as a measure of quality - rightly or wrongly!)

f). *We rarely give much thought to concrete's tensile strength (and we usually ignore it in design – certainly in ULS strength calculations)*

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Concrete & Cracking – the basics 2

The Institution of Engineers, Malaysia

WHAT WE DON'T OFTEN REALISE (AS MUCH AS WE SHOULD?) ...

1. Concrete cracks when it is subjected to **excessive tensile stress** (or strain)

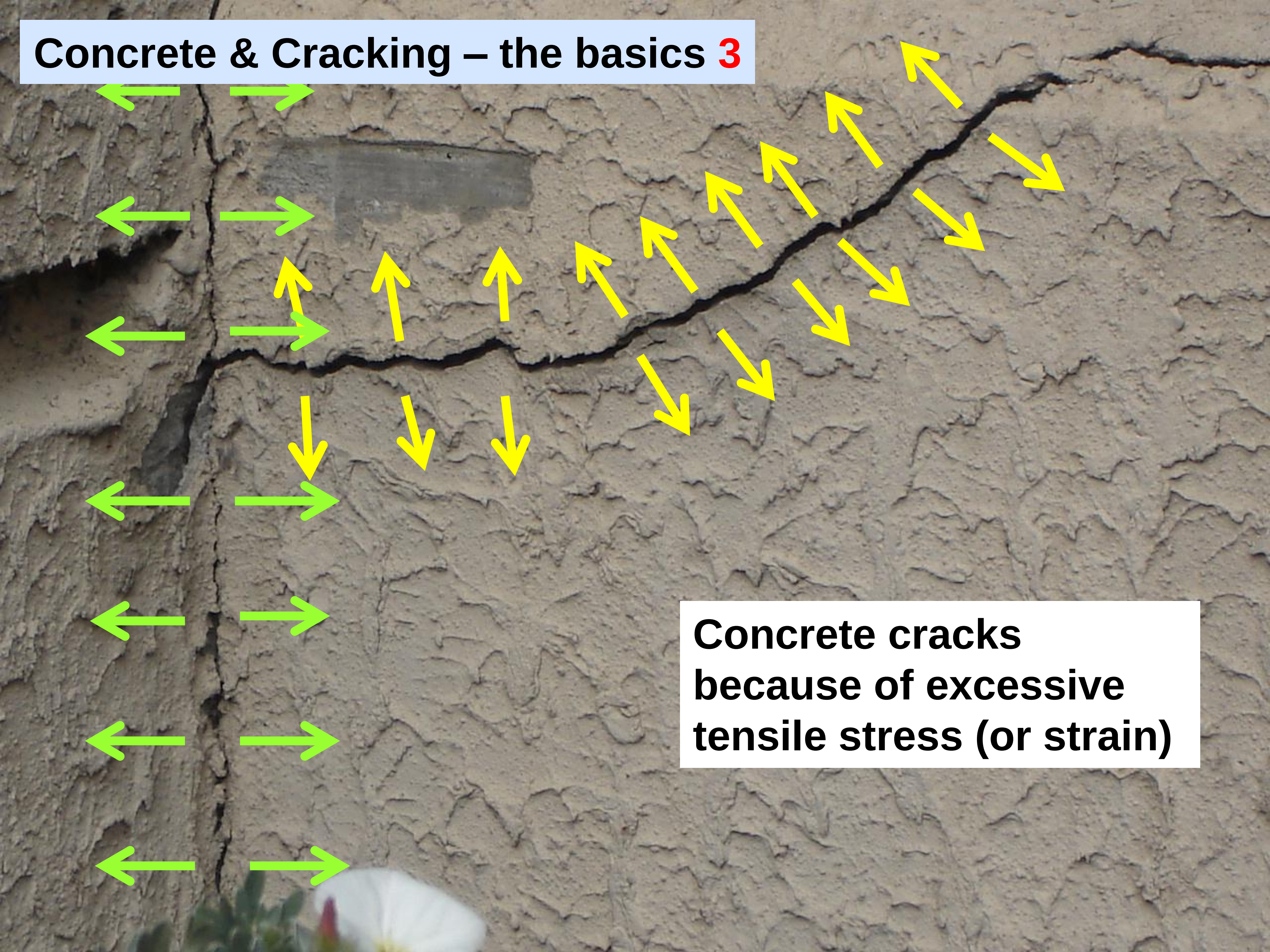
2. *Even though we **ignore the tensile strength** of concrete in most of our routine design calculations, it is **IMPORTANT***

3. Concrete's tensile strength is its **resistance to cracking**

4. *The (tensile) strength of concrete is VERY low during the first few hours/days – so **concrete is VERY SUSCEPTIBLE to cracking in the first few hours and days after pouring***

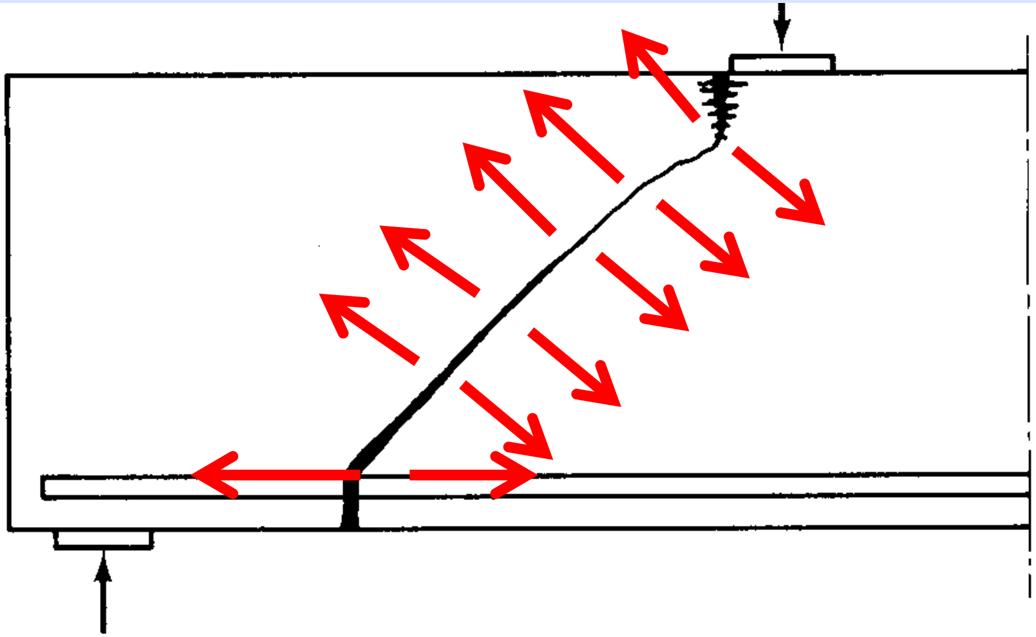
5. Tension (and therefore cracking) can occur in concrete in MANY different ways – HENCE, concrete can crack due to a variety of causes!

Concrete & Cracking – the basics 3



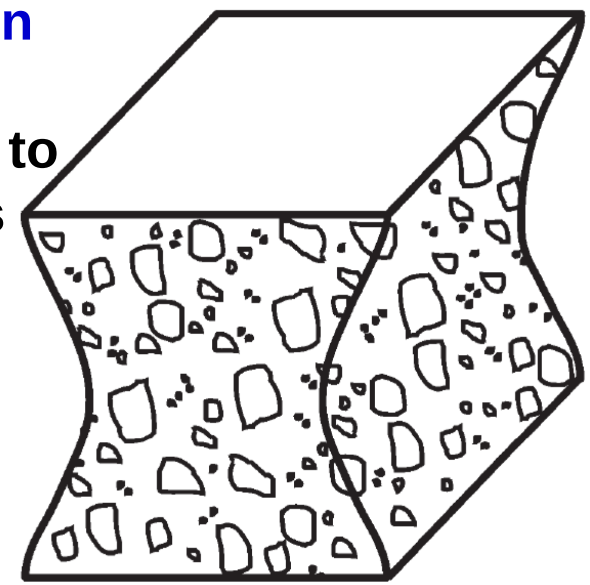
Concrete cracks because of excessive tensile stress (or strain)

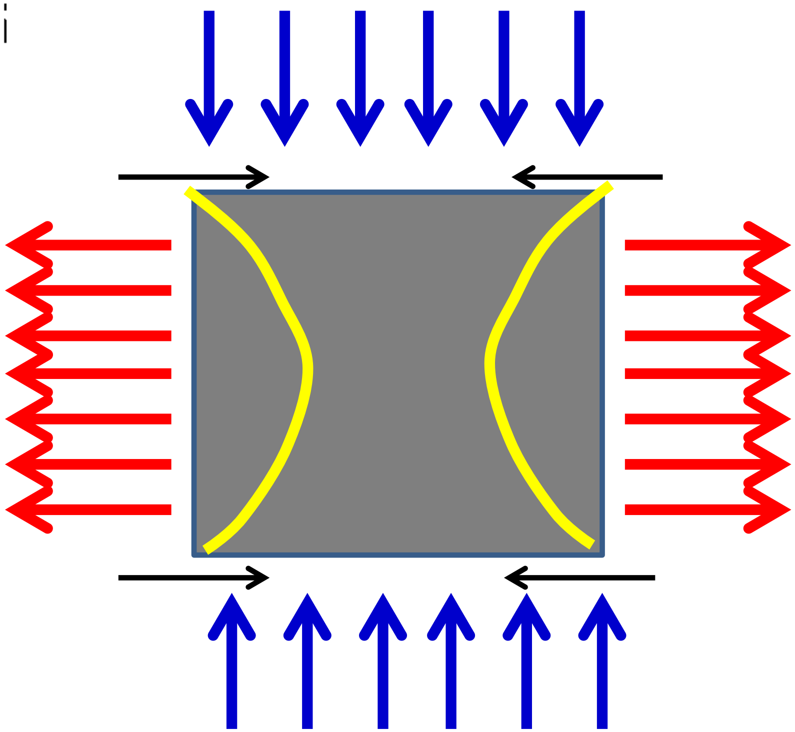
Concrete & Cracking – the basics 4



"**Shear failure**" = cracking due to tensile stress

"**Compression failure**" = cracking due to tensile stress





Concrete & Cracking – the basics 5

WHAT MANY OF US DON'T REALISE (OR PERHAPS HAVE FORGOTTEN?) ....

a). (Nearly) **all concrete cracks**!

b). *Hardened cement paste contains **micro-cracks** that form during the hydration reaction (cement + water)*

c). As the "E" value of concrete in tension is much lower (about 1/6th) of the "E" value of reinforcing steel, THEN **the concrete adjacent to the steel must crack before the steel can carry any significant stress**!

d). *We should EXPECT concrete to crack!*

It rarely lets us down!

Concrete & Cracking – the basics 6

Hence, we can address the issue of cracking in concrete by either:

1. **Reducing (or avoiding) tensile stress**

AND/OR

2. **Increasing the tensile strength of concrete (providing more resistance to cracking)**

These 2 key issues form the basic principles of crack control in concrete!

It is important to be PROACTIVE (be aware of the potential problems and deal with them in advance) rather than being REACTIVE = REPAIR OR STRENGTHENING!

Codes of Practice: Reflections 1

- Most concrete design codes of practice are now based on the principles of limit states design.

- **CP110 (launched in 1972) was the first limit states based code – it marked a significant change in the format of Codes of Practice.**

- **Previous codes** *(based on permissible stress design and elastic behaviour, e.g. CP114 for reinforced concrete)* - **much less prescriptive and detailed.**

- *In my opinion (and personal experience)* **engineers using the old codes needed to have a better overall understanding of all aspects of concrete – not all the information could be found in the code!** *(This does NOT automatically mean that older generations of engineers knew everything!!)*

Codes of Practice: Reflections 2

- **My impression is that many engineers "***brought up on/used to***" limit states based codes (BS8110, EC2, etc) tend to expect codes of practice to provide detailed guidance on (almost) everything?**

- **Possible incorrect view that "***If it's not in the code then it cannot be important***!" (or it might be forgotten or overlooked).**

- **Modern codes are not text books** *(and were never intended to be!) – they are codes of good practice.*

- **There is no substitute for experience (and the detailed knowledge brought by experience)!**

- **Before progressing further it might be useful to look at the GENERAL ASSUMPTIONS stated in the Eurocode (EN 1990) .....**

Codes of Practice: Reflections 3

The Eurocode (EN 1990 and all its constituent parts) is based on the following **general assumptions** (BS EN 1990, clause 1.3):

- *The choice of the structural system and the design of the structure is made by **appropriately qualified personnel**;*
- Execution (i.e. construction) is **carried out by personnel having the appropriate skills and experience**;
- ***Adequate supervision and quality control** is provided during design and during execution of the work, i.e. in factories, plants or on site;*
- The construction materials and products are used as specified in EN 1990 or in EN 1991 to EN 1999 or in the relevant execution standards, or reference material or product specifications;
- *The structure will be adequately maintained;*
- The structure will be used in accordance with the design assumptions

Codes of Practice: Reflections 4

- **We engineers like equations!**
- **Mathematics is at the core of our education – many of us tend to feel comfortable with** *equations = mathematical expressions of physical behaviour*. **We rely on them and trust them.**
- **Also, such equations can be readily built into design software** *(very convenient!)*
- **Many aspects of concrete behaviour can be readily "codified"** *(captured in the form of mathematical expressions).*
- **An example of this is structural cracking of concrete = cracking caused by applied load.**
- **CP110, then BS8110 and now EC2 provide guidance on designing to minimise the risk of structural cracking (an SLS check).**
- **With bridge design & design of water retaining/excluding structures, structural crack control often dictates the final design.**

Codes of Practice: Reflections 5

- IMPORTANT: there are many other causes of cracking – these are collectively called NON-STRUCTURAL CRACKS. They are caused by many different sources of tensile stress (other than stresses caused by the applied load) – see later.
- There is a common misconception about non-structural cracking!
- Some people think that non-structural cracks are “cosmetic” cracks - this implies they only affect the appearance of the structure – otherwise they are not important – THIS IS INCORRECT!
- The tensile stresses (and physical behaviour) that causes non-structural cracking cannot be readily described in the form of equations and, as a result, **there is no detailed guidance on how to address most causes of non-structural cracking in EC2** (or other codes).
- This does not mean that non-structural cracking can be ignored!

Codes of Practice: Reflections 6

- NOTE: In BS8110, the predecessor to EC2, non-structural cracking caused by early thermal effects and shrinkage (see later) was only considered in Part 2, “Code of practice for special circumstances”.
- This gives the impression that, in the 1980s and 90s (and before), many engineers were unaware of non-structural cracking.
- This was in spite of the fact that non-structural cracking of some form can occur in most forms of concrete construction (hardly “special circumstances”)

So what DOES EC2 tell us about cracking ....

Extract from BS EN 1992-1-1: 2004

(inc. February 2014 corrections)

Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings

(with reference to BS EN 1992-3 : 2006
Part 3: Liquid retaining and containment structures)

Clause 7.3 Crack control

Clause 7.3.1 General considerations ....

EC2 and Cracking 2

1(P) Cracking shall be limited to an extent that it will not impair the proper functioning or durability of the structure or cause its appearance to be unacceptable.

2. Cracking is normal in reinforced concrete structures subject to bending, shear, torsion or tension resulting from either direct loading or imposed deformations.

3. **Cracks may also arise from other causes such as plastic shrinkage or expansive chemical reactions within the hardened concrete. Such cracks may be unacceptably large but their avoidance and control lie outside the scope of this Section.**

4. Cracks may be permitted to form without any attempt to control their width, provided they do not impair the functioning of the structure.

5. A limiting value, w_{max}, for the calculated crack width, w_k, taking into account the proposed function and nature of the structure and the costs of liming cracking, should be established.

EC2 and Cracking 3

Cracking is normal in reinforced concrete structures subject to bending, shear, torsion or tension resulting from either **direct loading** or **imposed deformations**.

Comment: Direct Loading = structural cracking; Cracking caused by imposed deformations is a form of non-structural cracking.

IMPORTANT

Clause 7.3 gives some guidance on crack control estimates/calculations due to structural actions or DIRECT LOADING **BUT NOT for "imposed deformations"**

This is cracking due to restrained autogenous, drying and early thermal shrinkage – in my experience it is **EXTREMELY COMMON**!

This is a major omission in EC2!

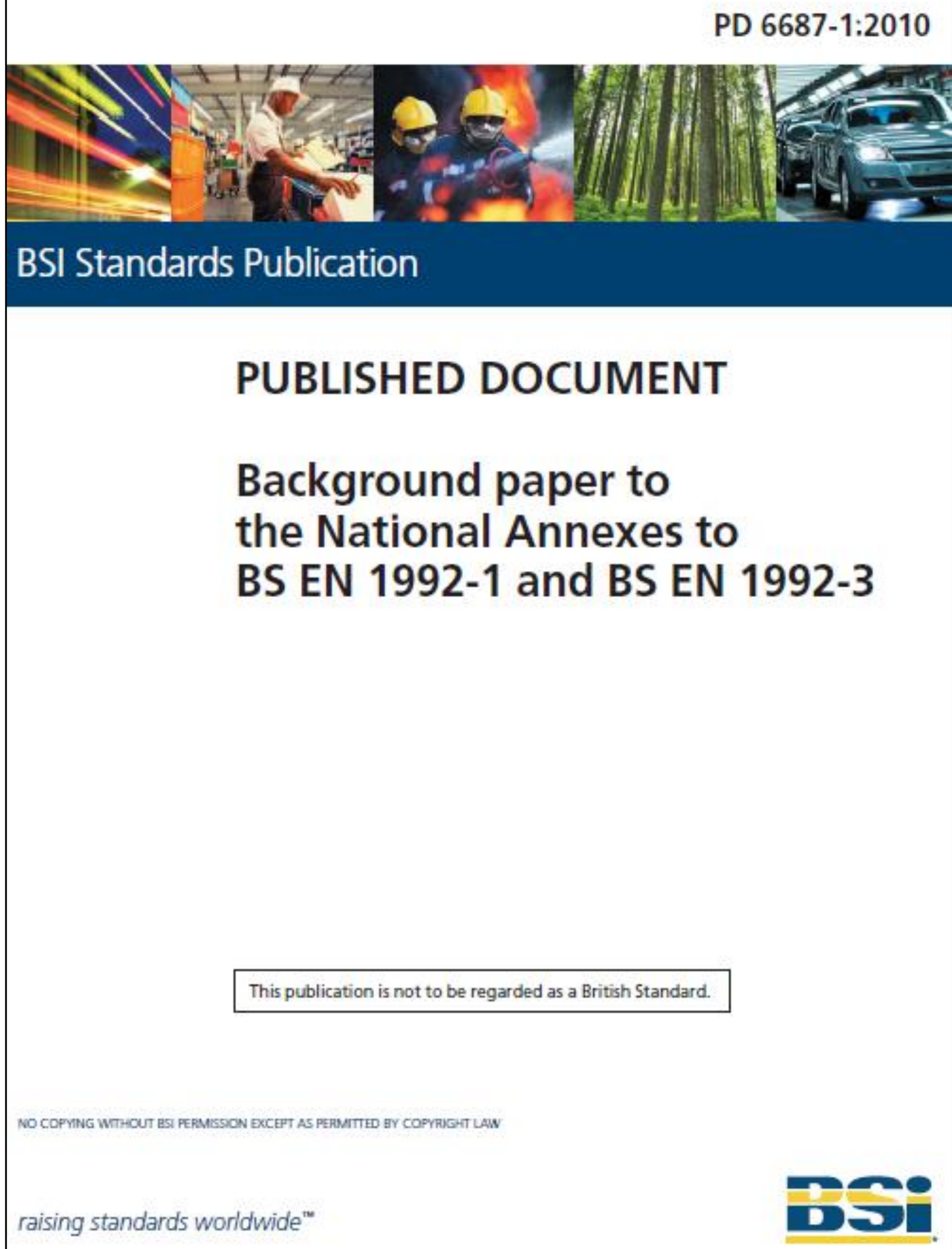
UK engineers have acknowledged this in a British Standards Institution publication known as a PUBLISHED DOCUMENT (or PD) ......

EC2 and Cracking 4

Crack width due to restrained imposed deformation

BE EN 1992-1-1:2004 *does not provide sufficient guidance on calculating crack width due to restrained imposed deformation* but it is covered in BS EN 1993-3:2006. CIRIA C660 deals with this topic more fully

So in the UK we use CIRIA C660 ......


PD 6687-1:2010

BSI Standards Publication

PUBLISHED DOCUMENT

Background paper to
the National Annexes to
BS EN 1992-1 and BS EN 1992-3

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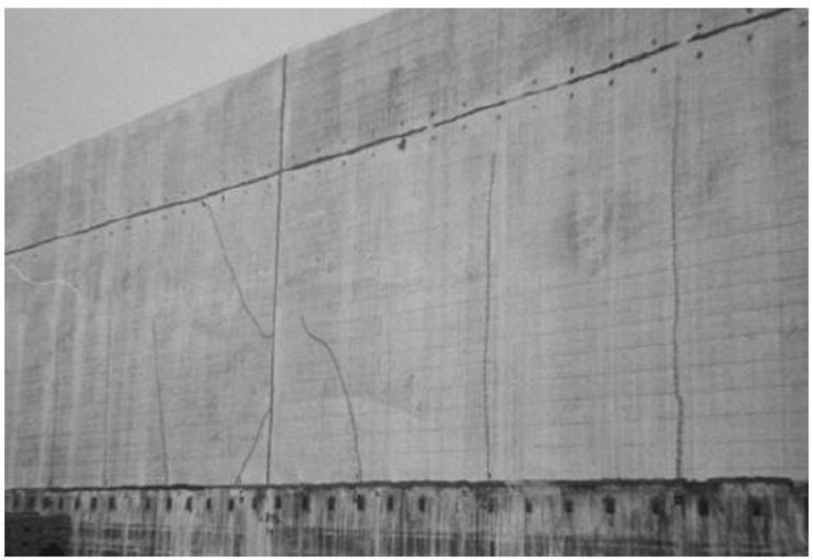
raising standards worldwide™

EC2 and Cracking 5

Construction Information Research and Information Association (CIRIA) report C660
by
P.B Bamforth,
2007 (re-printed in 2014)

Early-age thermal crack control in concrete



Important note: the design data provided in C660 is based on UK ambient conditions, cementitious materials (with partial cement replacements such as pfa) and data for a range of UK aggregates (e.g. coefficients of thermal expansion and tensile strengths)

Hence: **C660 is NOT DIRECTLY APPLICABLE to Malaysian conditions** **but** could form the basis of a future design guide for Malaysia?

EC2 and Cracking 6

1(P) Cracking shall be limited to an extent that it will not impair the proper functioning or durability of the structure or cause its appearance to be unacceptable.

2. Cracking is normal in reinforced concrete structures subject to bending, shear, torsion or tension resulting from either direct loading or imposed deformations.

3. **Cracks may also arise from other causes such as plastic shrinkage or expansive chemical reactions within the hardened concrete. Such cracks may be unacceptably large but their avoidance and control lie outside the scope of this Section.**

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5. A limiting value, w_{max}, for the calculated crack width, w_k, taking into account the proposed function and nature of the structure and the costs of liming cracking, should be established.

EC2 and Cracking 7

Cracks may also arise from other causes such as **plastic shrinkage** or **expansive chemical reactions** within the hardened concrete. Such cracks may be unacceptably large but their avoidance and control lie outside the scope of this Section.

Comments

- **EC2 acknowledges that there are other sources of tensile stress (or strain) that can cause cracking.**
- **It also acknowledges that these can be “serious” (unacceptably large)**
- **But no further detailed guidance is provided!**
- **Plastic cracking, in particular, is common in Malaysia – few engineers are aware that is can (and does) happen?**
- **Sulfate attack and carbonation or chloride induced corrosion of steel are expansive reactions within the hardened cement paste – very common!**
- **YOU HAVE BEEN WARNED! – see later**

EC2 and Cracking 8

So, in summary:

- EC2 provides guidance on dealing with structural cracking.
- BUT, although it (at least now) acknowledges that non-structural cracking can occur and can be significant ("unacceptably large"), there is no detailed guidance on how to control non-structural cracking – it is considered to be outside the scope of the code!
- As explained earlier, this is not unreasonable! The different mechanisms that cause non-structural cracking cannot be defined in the form of useful or reliable equations.

Here next, in PART 2, is an overview of common forms of non-structural cracking ....

This will be followed by PART 3 – a brief overview on how you might deal with non-structural cracking before, during and after construction.

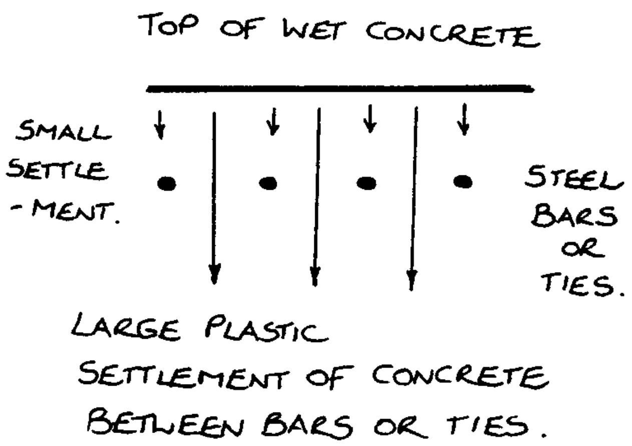
Part 2:
Some common forms of non-structural cracking

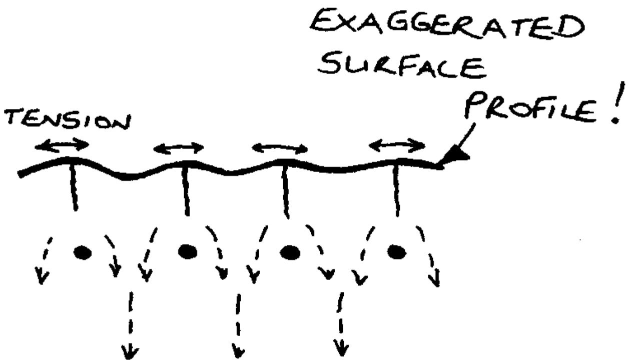
(cracking NOT caused by applied loading)

Note: cracking caused by poor detailing, loss of support caused by scour/flooding or by foundation failure or excessive movements are all considered to be structural in nature.

Plastic Cracking *(few hours after pouring – cracking in wet concrete)*

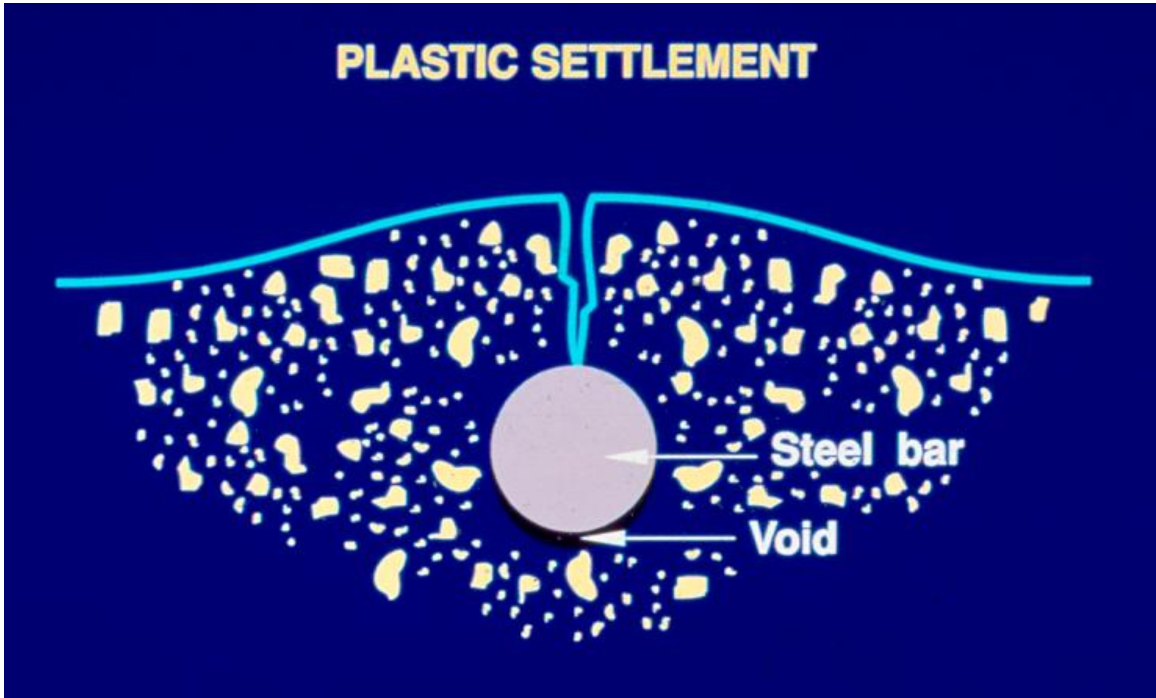
Plastic settlement cracking:





Occurs when concrete exhibits bleeding

Tensile stresses can occur in the wet concrete caused by obstructions to bleed movement

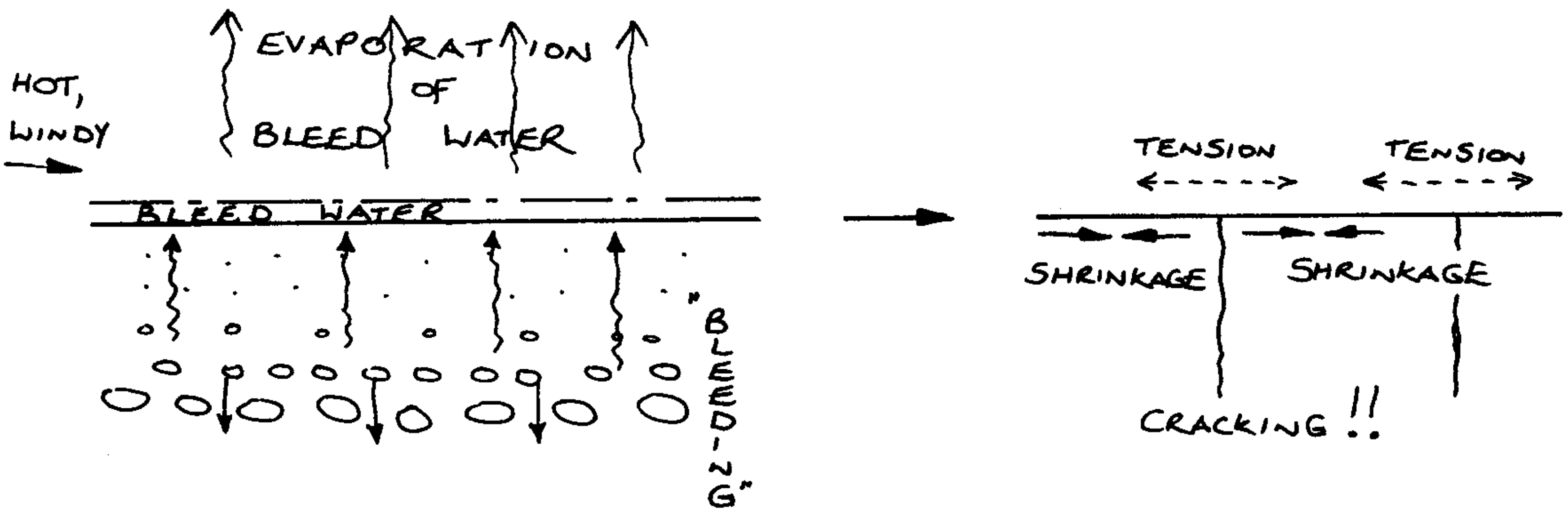


Plastic Cracking *(few hours after pouring – cracking in wet concrete)*

PLASTIC SHRINKAGE CRACKING: This is a very common form of cracking – thin slabs are particularly vulnerable.

It also occurs when bleeding of the concrete occurs.

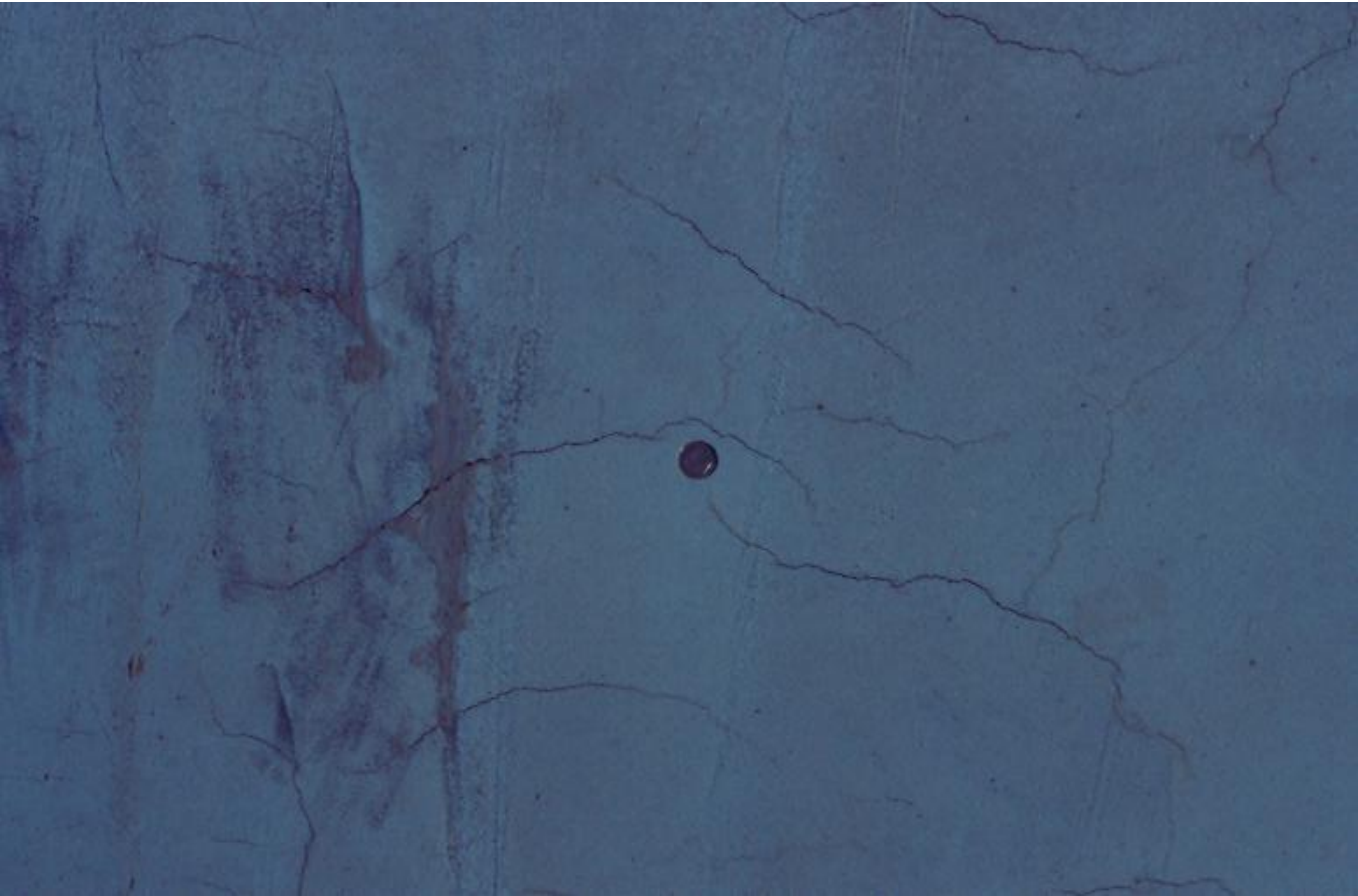
Tensile stresses are caused when the bleed water evaporates from the surface of a slab in hot, dry, sometimes windy conditions leaving high cement content material with little coarse aggregate at the surface resulting in shrinkage and cracking



The tensile stresses created are VERY SMALL – but remember that the tensile strength of the concrete, at this stage, is also VERY SMALL

Example of plastic shrinkage cracking – deck of portal bridge in UK

These cracks found over the entire surface of the deck !



Cracking due to expansive chemical reactions

Examples

Sulfate attack (formation of **expansive** ettringite) – sulfates from some soil types; ground water, sea water. The cement paste suffers a major loss of strength (it crumbles and the concrete breaks up)

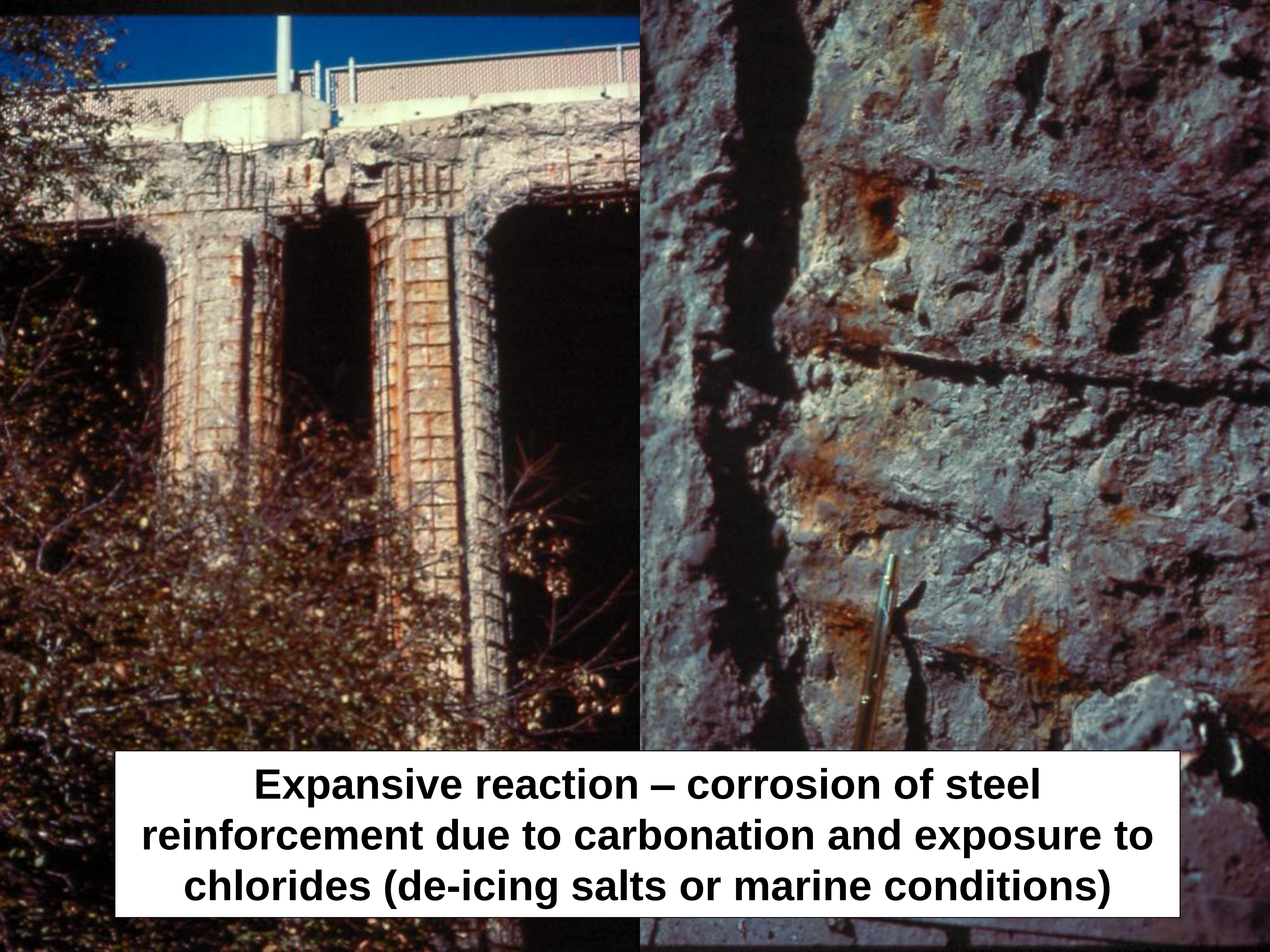
Alkali-Silica reaction (**expansive** reaction between alkali salts in cement and silica in aggregates) – VERY DISRUPTIVE! Severe cases of ASR – demolition 15 years after construction!

Corrosion of cast-in steel reinforcement (carbonation and/or chloride-induced corrosion) – formation of **expansive** ferric oxide and ferric hydroxide compounds (= rust). Reinforced or prestressed concrete with corroding steel can lead to collapse!

Some specific examples ....

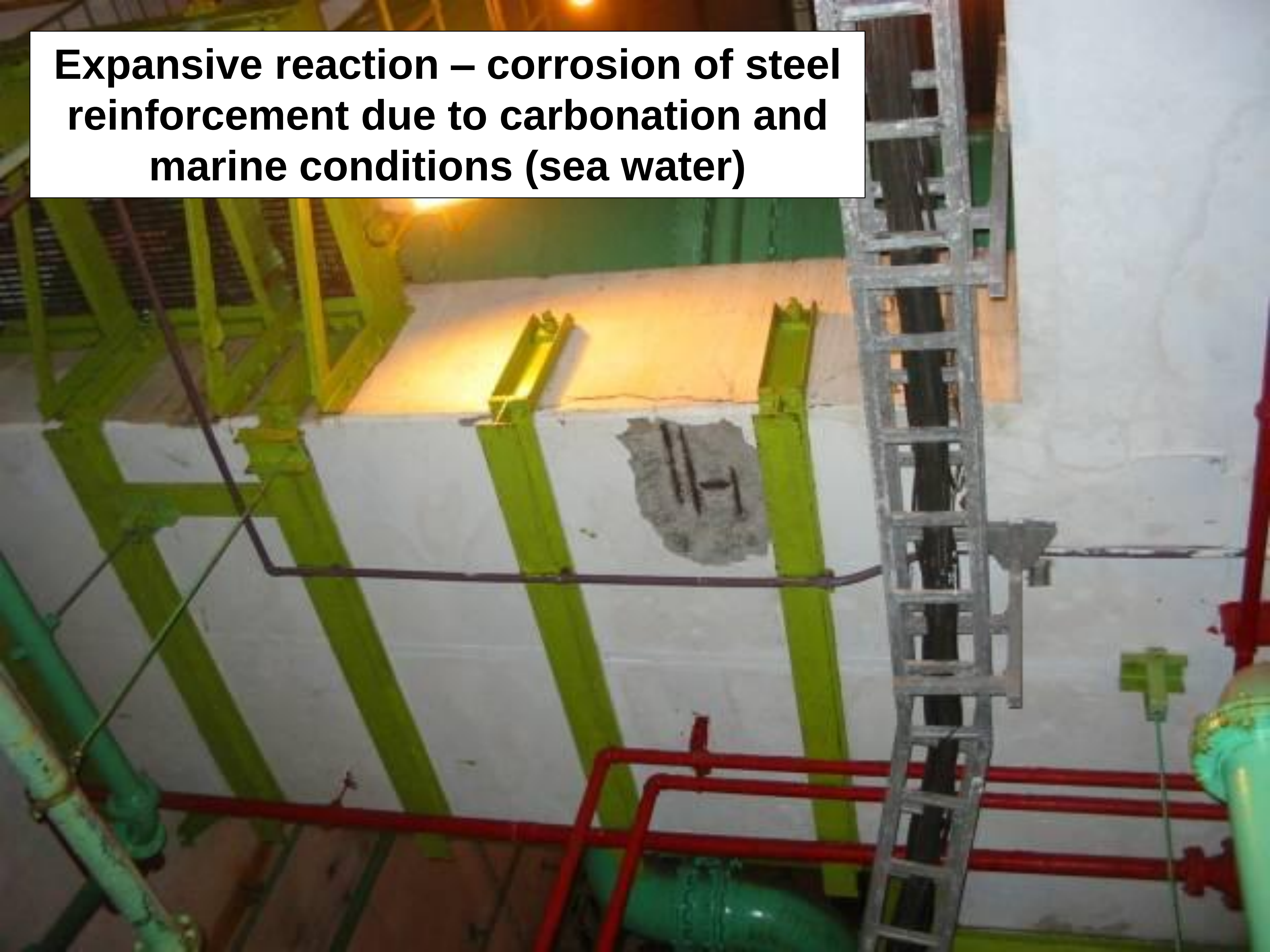
Chemical attack - sulfates

Alkali-Silica Reaction



Expansive reaction – corrosion of steel reinforcement due to carbonation and exposure to chlorides (de-icing salts or marine conditions)

Expansive reaction – corrosion of steel reinforcement due to carbonation and marine conditions (sea water)



Gardiner Expressway, Toronto, Canada

Context: the principal artery of Canada’s largest city

Gardiner Expressway, Toronto, Canada

Gardiner Expressway, Toronto, Canada

Extensive corrosion-induced cracking of the reinforced concrete piers and crossheads (note also the corrosion of the steel beams!)

Principal cause – the use of sodium chloride (salt) as a de-icing agent in winter!

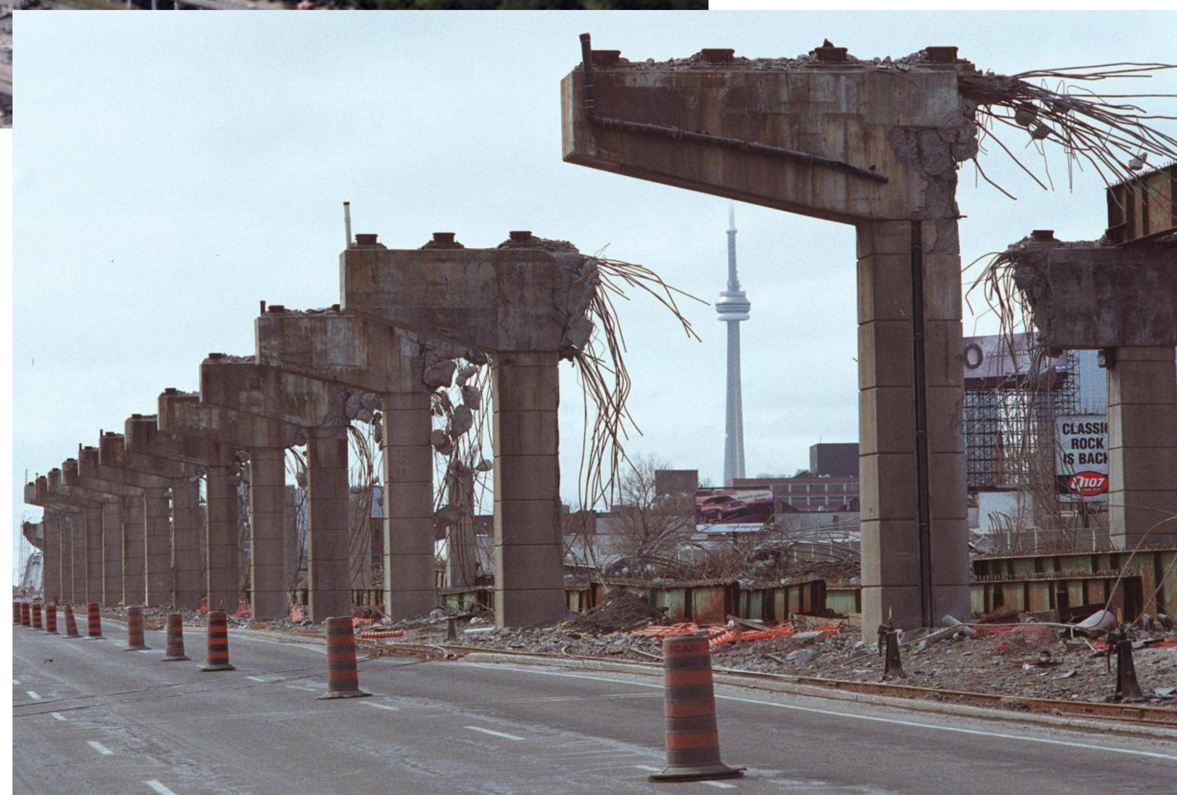
Gardiner Expressway, Toronto, Canada


Gardiner Expressway, Toronto, Canada
Repairs applied to previous repairs have failed!

Gardiner Expressway, Toronto, Canada

Demolition (and replacement) – the inevitable?

Source: The Globe and Mail, Toronto, Canada



Exposure to chloride salts *(3-span RC footbridge, Bondi Beach, nr. Sydney, Australia)*

Exposure to chloride salts – marine atmosphere *(several phases of repair – ineffective & uneconomical? Unsustainable?)*

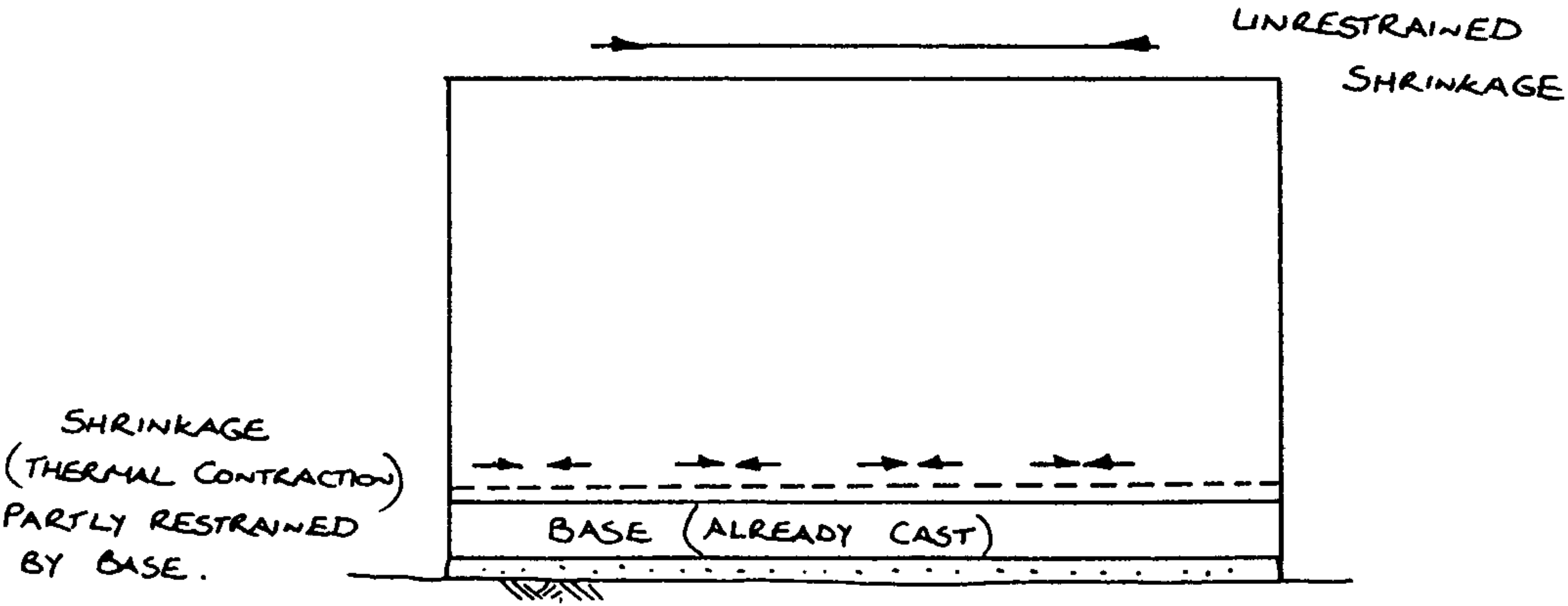
The bridge in all its “glory”!

(Marine environment: No de-icing salts!)

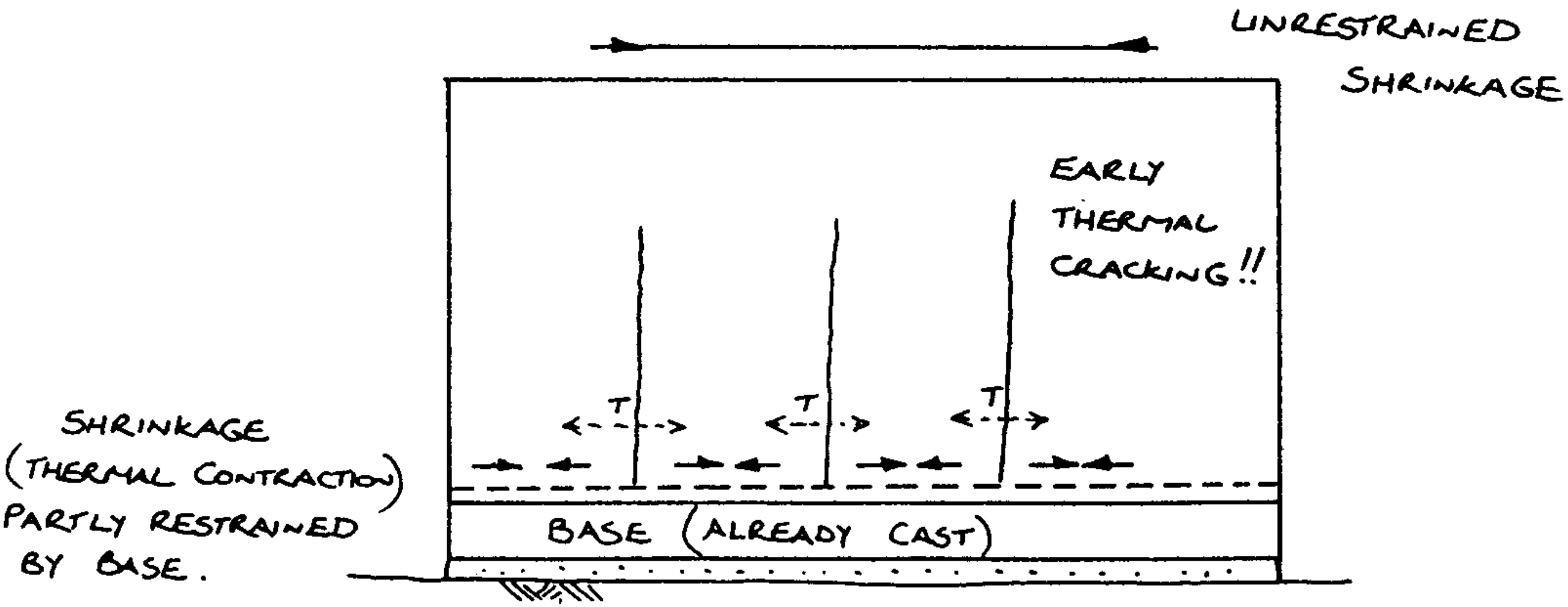
Restrained Deformation Cracking - Introduction

- **Non-structural cracking in concrete is also caused when the concrete contracts or shrinks and is restrained (or partially restrained) from doing so.**
- **Such restraint is usually provided either by the existing ground (in the case of a foundation or cast-on-grade floor slab) or by the previously cast concrete.**
- **The restraining effect of the ground or previously cast concrete creates tensile strains. If the tensile strain exceeds the tensile strain capacity (or tensile strength) of the concrete, the concrete cracks.**
- **For example, consider the casting of a wall on a previously cast foundation ......**

Restrained Deformation Cracking - Introduction



Restrained Deformation Cracking - Introduction



Restrained Deformation Cracking - Introduction

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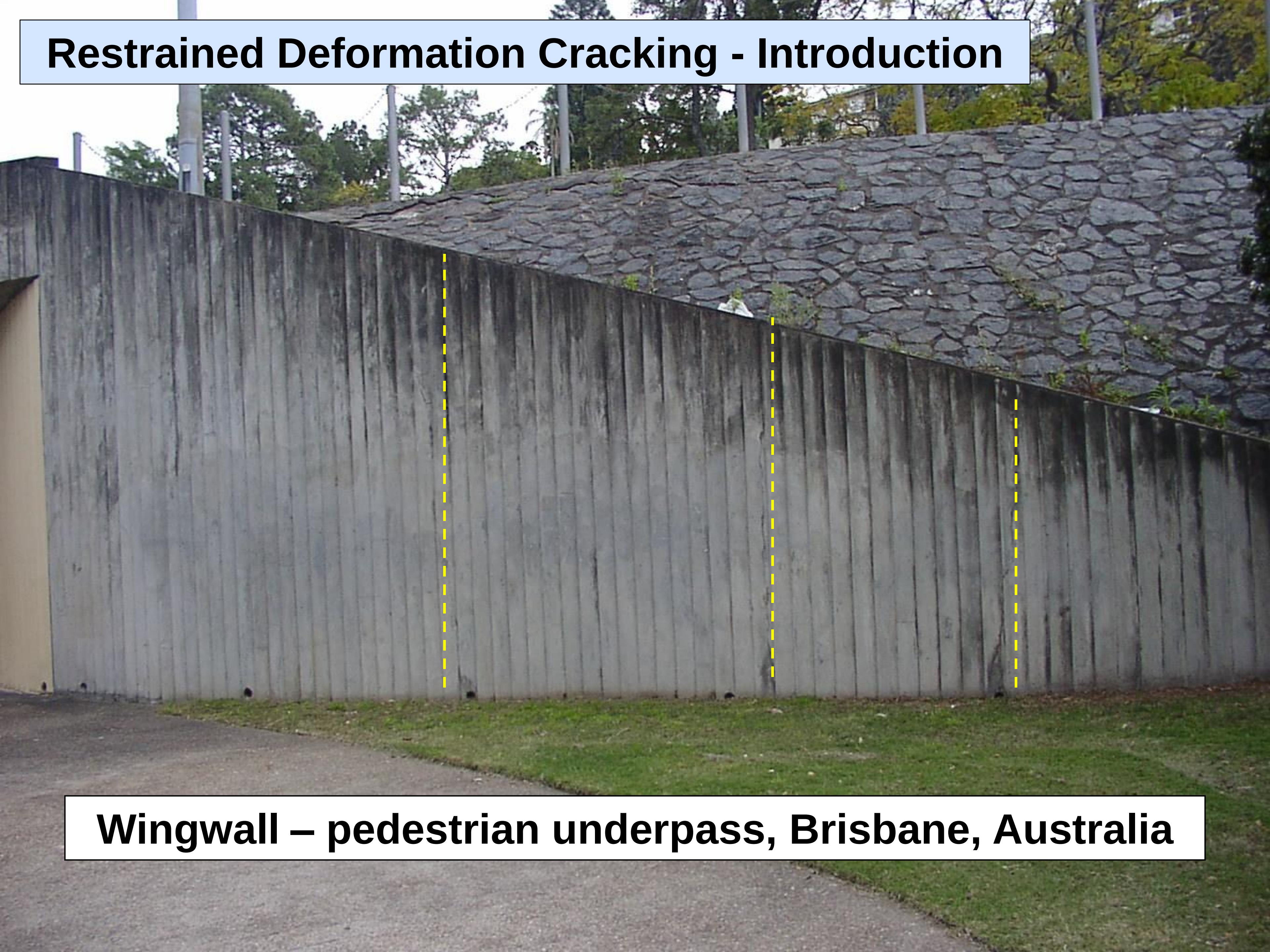

Wingwall – pedestrian underpass, Brisbane, Australia

Restrained Deformation Cracking - Introduction

Part 3:

Actions

Before, during and after Construction

If you are aware that:

- Plastic movement of the wet concrete can occur;
- Expansive reactions can occur in the hardened concrete (e.g. Sulfate attack, ASR, rebar corrosion);
  and
- Thermal and shrinkage movements can occur in the first few days after pouring

...... THEN you can do something before it’s too late!.

IGNORANCE means:

You’ll end up having to REPAIR the cracked concrete

REPAIR =

- re-instating lost structural integrity;
- prevention of leakage;
- repair of disrupted finishes;
- dealing with future durability problems (more expensive repair, strengthening or, worse still, demolition!);
- dealing with the unacceptable appearance by providing cosmetic coatings (to hide the cracks for a limited period of time? Expensive and a future maintenance liability?);
- extra cost;
- disruption to business;
- etc.

and

UNHAPPY CLIENTS!

Plastic Cracking *(few hours after pouring – cracking in wet concrete)*

Plastic cracking controlled by;

Concrete mix design (low bleed mixes; well graded aggregates = cohesive mixes + *possibly* the use of viscosity modifiers [these tend to be used in self-compacting concrete which can be very susceptible to bleeding and segregation);

Experience on site – **be aware that plastic cracking CAN occur** – visually inspect the poured concrete regularly for signs of plastic cracking then, POSSIBLY, re-vibrate or re-float the surface concrete or work a cement-rich slurry into the hardening concrete

IF THE POSSIBILITY OF PLASTIC CRACKING IS IGNORED – next day start to explore crack repair strategies!

NOTE: unrealistic to expect EC2 guidance on controlling plastic cracking?

Cracking due to expansive reactions in the hardened concrete 1

Before starting construction ...

- Check sources of aggregates carefully to reduce risk of ASR
- Undertake chemical analysis of soil and groundwater – check for acid, sulfate and chloride levels – identify the degree of exposure as part of the initial ground investigation.
- Consider the use of ADDITIONAL PROTECTIVE MEASURES (e.g. Cathodic protection, corrosion inhibitors, use of specialist cements, use of partial cement replacements, use of protective surface coatings, etc).
- Ensure that construction is independently checked? Initial cost worthwhile? Liaise with Client at an early stage. (Design and Build projects – concerns about long-term quality?)

Cracking due to expansive reactions in the hardened concrete 2

- Follow the usual good practice regarding concrete mix design (low water:cement ratios); good compaction, sufficient cover to meet the exposure conditions, adequate compaction, good curing (particularly important if using partial cement replacements);
- Use low corrosion risk materials (stainless steel, possibly frp reinforcement?);
- Try to avoid the need for steel reinforcement in high corrosion risk areas (use mass concrete for sea walls?);
- Check water supplies for chemical content;
- Check aggregate supplies for chemical content (are they free of chlorides?);
- Minimise the risk of corrosion.

Etc.!

Restrained Deformation Cracking – Actions 1

- It is common practice to control such cracking by providing extra steel reinforcement to counter the tensile stresses caused by the restraint.
- Such reinforcement distributes the tensile strains along the length of the reinforcement so that crack widths are kept to an acceptable surface width. What is acceptable depends on aesthetic, durability and functional requirements (see EC2 clause 7.3.1).
- As an alternative, the degree of restraint can be reduced by providing movement joints. This will result in the need for smaller areas of steel.
- Using low heat of hydration cements (partial cement replacements) and controlling thermal gradients within the concrete also help.

Restrained Deformation Cracking – Actions 2

Restrained Deformation Cracking – Actions 3

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- Consider specifying a minimum tensile strength for your concrete (measured using the modulus of rupture or cylinder splitting test).
- If you want concrete that can resist cracking surely it makes sense to use a high tensile strength concrete?
- If available, use crushed rock aggregates rather than smooth surface aggregates?
- Avoid high fines contents (“dust” can coat the coarse aggregates reducing the bond with the cement paste and, therefore, the tensile strength of the concrete).
- EC2 used in conjunction with CIRIA Report C660 “Early-age Thermal Crack Control” by P.B.Bamforth (2014) provides designers with some guidance (but it is based on UK conditions).

Part 4:
Summary and Lessons

Summary and Lessons 1

- Cracking is caused by excessive tension (the tensile strength of concrete IS important = concrete's resistance to cracking).
- Concrete does not have a large tensile strength and it is a brittle material - it is, therefore susceptible to cracking, particularly in its early stages (VERY low tensile strength).
- Nobody wants concrete to crack – but it will crack! (EC2 tells us that cracking is "normal")
- The challenge to the construction industry is to CONTROL CRACKING so that it is acceptable (i.e. not excessive).
- Most engineers are familiar with structural cracking and tend to address this as part of the design process (with guidance from EC2 and its predecessor codes)
- Indeed ..... EC2 provides SOME guidance on crack control (minimum areas of steel reinforcement; guidance on designing reinforcement to control structural cracking @ SLS) + CIRIA C660 can be used to address cracking caused by restrained deformations (often requires more than "minimum steel").

Summary and Lessons 2

- Non-structural cracking is a major source of deterioration and loss of performance in concrete structures
- Most non-structural cracking cannot be described by equations – knowledge and understanding gained from experience is required!
- EC2 warns us about non-structural cracking but cannot provide detailed guidance on how to minimise or control it!
- EVERYONE involved in the design, specification and construction of concrete structures has a collective responsibility to control cracking to an acceptable level .....
- Unfortunately not everyone is aware of the many common forms of non-structural cracking (partly because little/no guidance can be provided in our codes of practice?). THIS IS A BIG PROBLEM!
- Raising awareness and improving understanding are essential.

Some final questions .....

- **Does everyone in the construction industry in Malaysia understand how concrete cracks and how to control cracking?**
- **Is everyone aware of non-structural cracking?**
- **Is enough done before and during construction to minimise the risk of non-structural cracking?**
- **Is the quality of concrete construction in Malaysia OK? OR is there a problem?**
- **Is time and cost the major obstacle/problem?**
- **Does it *have* to cost much more money for better quality or is it more about employing more competent engineers?**
- **Is it OK to carry on without change?**
- **IF NOT - where do we (you) go from here?**
- **Do you shrug your shoulders and accept "defeat" saying that nothing can be done? There are too many obstacles?**
- **Another (slightly cynical, irresponsible and unprofessional view?) view: more defects and problems = more work for engineers!**

A few more final questions .....

OR:

- **As Malaysia's professional engineering body, should YOU try to improve matters? (If you don't then who will?)**
- **Should the IEM and BEM jointly ensure that degree programmes cover topics such as cracking, construction, durability, etc?**
- **If so, HOW is this checked/ensured? (the accreditation process?)**
- **Should there be a mandatory requirement for all graduate trainees to have a minimum period of site experience before becoming PE qualified?**
- **Are further qualifications and training required (beyond 1st degree) for concrete specialists to be engaged in design and construction? How can competence be demonstrated?**
- **Is a Bachelor's degree sufficient for professionally qualified engineers? (NOTE: in the European Higher Education Area = 48 countries including the UK, Masters level study is the minimum requirement!)**

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Want to know more?

I am delivering a 2-day seminar on Successful Concrete Rehabilitation and Repair for Applied Technology on 8th and 9th August (Armada Hotel, PJ).

I will be delighted to see you there!

The Institution of Engineers, Malaysia

Questions ?

(and answers?!)