Highways England Moonshot: Call for Research Ideas

Post-Tensioned Bridges Management

1. Call for research ideas

On behalf of Highways England, we would like to invite you to submit your suggestions for new research ideas with the potential to transform the way we detect and measure corrosion in steel structural elements buried in concrete. The aim is to make this a reliable and automated process such that data on corrosion of all buried steel elements in an existing bridge can be captured, stored and used to facilitate timely maintenance decisions.

This ask forms part of a wider "Moonshot" which has recently been instigated by Highways England to transform the way Highway England undertakes inspections and monitors structures and increase predictive analytics capability on existing post-tensioned structures. As part of this moonshot, Highways England wants to invest in research proposals that could drive this step change. Therefore, we are looking for ideas that are likely to necessitate new lines of research, rather than looking for incremental improvements to existing techniques that address only small aspects of the problem or have limited applicability across different bridge types.

All ideas received will be reviewed against the overall Moonshot objectives and those with the greatest potential may be selected as research projects to be either directly funded by Highways England or backed by Highways England through other funding routes such as EPSRC. There may also be opportunities for trials on Highways England's bridges and publicity opportunities.

The remainder of this calling note provides more detail on what we require and further background to this work. It is broken down as follows:

- Section 2 – Background
- Section 3 – Problem Statement
- Section 4 – Desired Outcomes
- Section 5 – The specific request for contributions & how to apply

2. Background

The greatest threat to our existing road and rail bridge infrastructure is corrosion of steel elements. Corrosion affects steel bridges and concrete structures (reinforced with embedded tensioned or un-tensioned steel bars and wires) alike. Corrosion of embedded steel in concrete is usually caused by the ingress of water and oxygen to the steel surface, exacerbated by the presence of contaminants such as chlorides in the water and also the gradual carbonation of the concrete due to the exposure to atmospheric CO_2 which removes the passivating effect of the alkaline concrete which initially protects the steel.

Corrosion can sometimes be seen directly by the human eye, such as on steel bridges with surface corrosion; this is not the focus of this project as steelwork corrosion can often be prevented through inspection of the paint system and re-application as necessary.

Corrosion of steel within concrete structures cannot be reliably seen at the concrete surface, but there may be signs of reinforcement corrosion at the surface, such as cracking, delamination and spalling of the concrete cover when the rusting process is expansive and rust staining of the concrete as corrosion products leak through cracks in the concrete (Figure 1). By the time these signs are observed, corrosion is usually well advanced and the opportunity to prevent it has been missed. Even when corrosion damage is detected, it is very difficult to determine the extent of the damage reliably without tactile inspection and intrusive removal of concrete to actually see and measure it; an activity which itself further weakens the bridge. The corrosion damage may also lead to reduced load-carrying capability and the need for repair and strengthening.

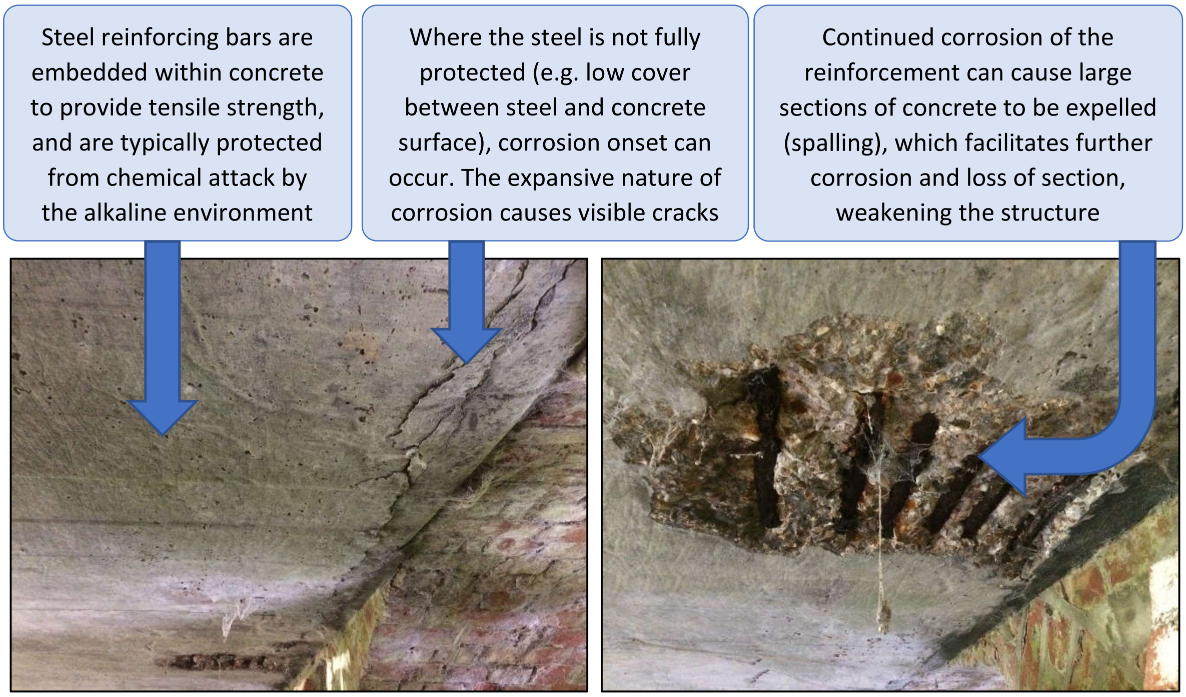

Figure 1 – Reinforcement corrosion-induced cracking and concrete spalling in a normally-reinforced concrete deck slab

A greater challenge is presented by corrosion of high strength steels used for prestressing and all steels in the presence of chlorides. Anaerobic corrosion can occur which does not give rise to expansive rust products and hence no surface crack or spalling. Also the presence of chlorides leads to local corrosion pitting that again may not cause sufficient rust product to cause spalling and may also contribute to hydrogen embrittlement. The strength of the steel is then weakened by both the loss of cross-section and the embrittlement of the remaining steel. Once again, the damage is difficult to reliably measure without removal of concrete to measure it and embrittlement cannot currently be measured without removing steel samples for laboratory testing (Figure 2).

The risk of steel reinforcement corrosion can be predicted with varying accuracy and levels of confidence by carbonation and chloride testing and half-cell potential surveys (1) (2), but these require human access to the bridge and contact with all its surfaces; carbonation and chloride tests are also intrusive, requiring concrete samples to be removed and the results are valid only for the area of removal. History has shown that these methods of inspection and investigation are not fully effective in identifying problems and stimulating action because of the extent of testing required to monitor a whole bridge and the difficulty of accessing all such areas. A diagrammatic representation of the current state-of-the-art technologies employed in the industry are shown in the infographic presented in Appendix A.

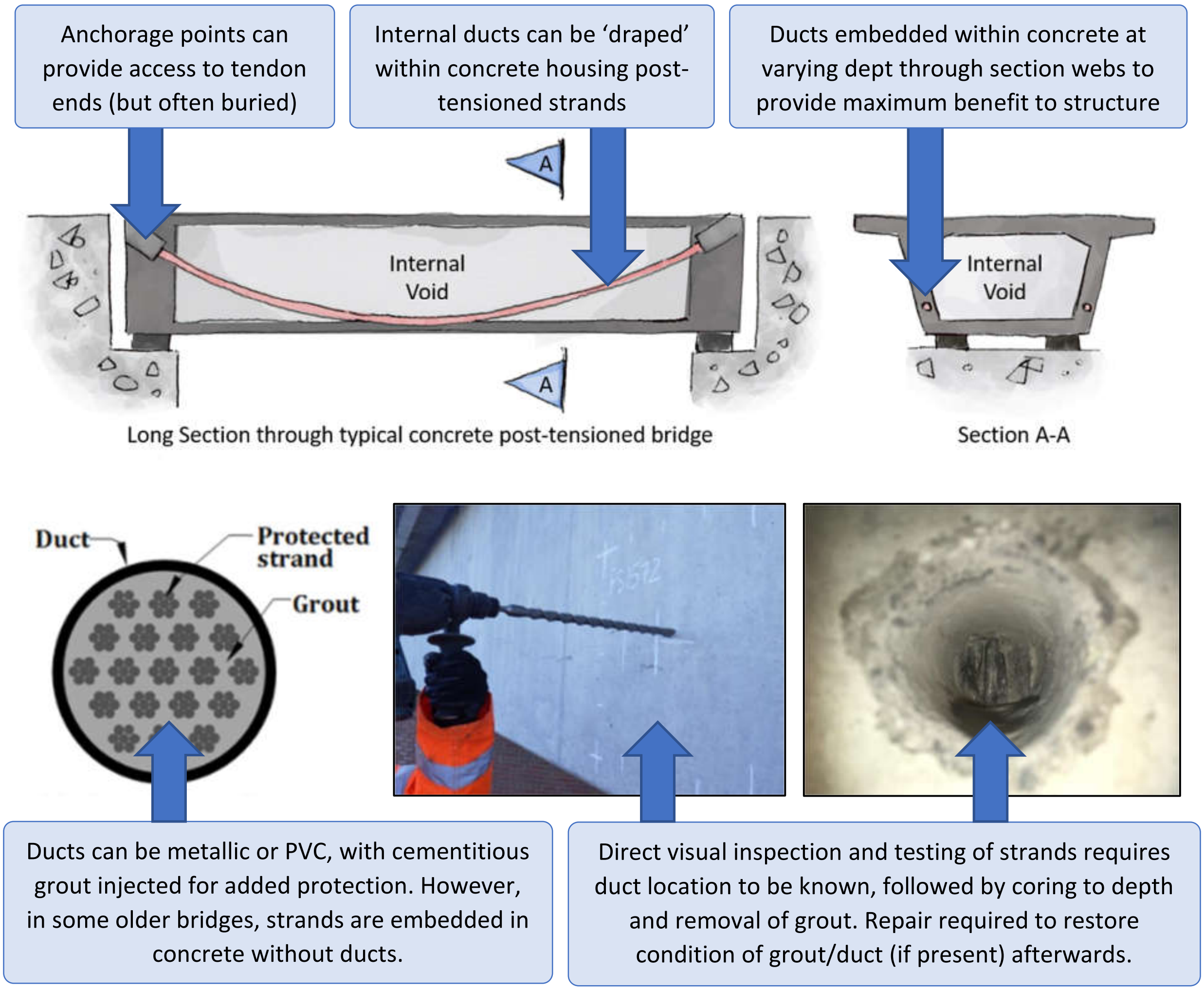

Figure 2 - Typical Post-Tensioned Duct/Strand Layout within Bridge and Intrusive Investigations

3. Problem Statement

In simple terms we need a method to identify for each concrete bridge with buried steel tension elements (particularly encased post-tensioned members):

1. **if the conditions for corrosion exist and how severe they are;**
2. **if corrosion is actually occurring; and,**
3. **how much corrosion has occurred and what loss of strength results in the elements affected.**

We want to reliably detect the corrosion of steel in concrete and the conditions which cause it, such that appropriate preventative maintenance action can be taken before conditions deteriorate to the point at which corrosion can begin. Where corrosion has already begun, we need to be able to identify the location of such corrosion and measure the reduction that has occurred in the steel cross-section to allow the calculation of residual strength. This information needs to be determined continuously or at sufficiently frequent intervals that deterioration (or the potential for deterioration) can be tracked, and safety can be monitored in effectively real time.

There are already strategies and technologies to address the above, but they rely heavily on human intervention to gather the information (and as such are unaffordable to do comprehensively), on intrusive techniques (which can further weaken the structure in the process), and on a series of different technologies with different degrees of maturity and reliability (none of which can deliver the required results in all situations at present). There is no single approach to monitoring the conditions for and detecting deterioration that is either reliable or affordable to deploy on all bridges.

A state-of-the-art review of what is currently done to detect and assess corrosion damage, including what technologies are used and their varying states of maturity, is included in the accompanying document (3). Examples of the current approach to addressing the challenges are as follows, but it is emphasised that they are not exhaustive and **do not** deliver the outcomes needed by industry (which are defined in the next section):

1. **Identifying if the conditions for corrosion exist and how severe they are:**
    - Look for visible signs of water ingress
    - Identify high chloride levels in the concrete, carbonation of concrete near the reinforcement, acidic conditions via pH metres
    - Identify areas of poor corrosion protection
2. **Identifying if corrosion is actually occurring:**
    - Look for delamination, spalling or rust staining of concrete
    - Use corrosion probes to identify electrical activity associated with corrosion
    - Intrusive investigation to remove concrete to look at the embedded steel
    - Acoustic emission monitoring – mainly to listen for wire and bar breaks
3. **Identifying how much corrosion has occurred:**
    - Intrusive investigation to remove concrete to look at the embedded steel
    - Use established scanning techniques, all of which have limited applicability e.g. X-ray
    - Use less developed scanning techniques e.g. magnetic flux leakage

4. Desired Outcomes

Highways England seeks an approach to managing concrete bridges with buried steel elements; particularly encased post-tensioned tendons, which:

- identifies if the conditions for corrosion exist and how severe they are; if corrosion is actually occurring; and how much corrosion has occurred, so as to enable the resulting loss of strength to be determined and / or,
- enables gathering and recording this information continuously or at sufficiently frequent intervals (e.g. during the 2-year cycle of bridge inspections) that interventions can be made ideally before damage occurs, but also that pre-existing damage and its rate of deterioration can be determined with interventions before safety is compromised and,
- does not require closures of the highway to gather the information other than at initial installation of any permanent sensing / measuring devices required to be retrofitted to existing bridges (but ideally not even then)
- is affordable, such that the costs per bridge in say a 5-year period are comparable to existing available maintenance budgets per bridge and,
- is reliable in terms of its consistent data recording accuracy or for imbedded sensors will continue functioning over the residual life of a bridge and,
- is reliable in terms of the accuracy of the data it captures such that there is a quantifiable level of accuracy (e.g. % tolerance on loss of section from corrosion) with the ability to identify and monitor trends in deterioration, potentially benchmarking against other identical structural elements on the same structure and,
- Installation imparts minimal damage and maintenance imparts zero damage to the structure.

It is acknowledged that it is highly unlikely that a single solution will suddenly emerge that provides all the above outcomes but, equally, no combination of currently available techniques and technologies has been identified to address them either. The intent therefore is, rather than to continue to try to find a use for existing technologies, to work from the fundamental requirements to identify scientific techniques that could be harnessed to develop a solution to one or more of the three fundamental problems from Section 3 (do conditions for corrosion exist, if it is occurring and if so, how much).

Initially we are interested in identifying all possible techniques for further development. They will then be assessed against their potential to deliver the outcomes required, specifically their potential to:

- gather and record the relevant information at appropriate intervals without asset closures
- be made affordable for wholesale use, even if initial concepts and prototypes are not commercially viable
- be developed into reliable techniques in terms of resilience and accuracy

5. The specific request for contributions & how to apply

If you are interested to contribute your ideas for potential funding or other support by Highways England, then please use the online form (linked below) with the following information:

1. Your organisation
2. Your name, role and contact details (email and telephone)
3. Which of the three problem statement(s) your research idea addresses:
   - *If the conditions for corrosion exist and how severe they are;*
   - *If corrosion is actually occurring; and,*
   - *How much corrosion has occurred and what loss of strength results in the elements affected.*
4. Brief description of your research idea (please try to limit this to 1000 words)
5. Whether the expertise for this research exists in your organisation
6. Brief details, if any, of similar research you are engaged in and with whom (300 words)
7. If any research related to points 4 or 6 is currently underway already, indicate broadly how progressed this research is, and the potential timeframes involved.
8. Whether you would be interested in principle in advancing this research if it was selected for Highways England backing.

Please use the online form for submissions: https://bit.ly/2YeB8cr by 26/02/21.

Responses will be reviewed by a Highways England panel led by Vlad Palan and Chris Hendy.

Please speak to **chris.mundell@atkinsglobal.com** for any queries you may have.

6. References

1. **UK Bridges Board.** *Inspection Manual for Highway Structures - Volume 1: Reference Manual.* London : TSO, 2007.

2. **Highways England.** *Repair and Management of Deteriorated Concrete Highway Structures.* s.l. : Highways England, 2019. CS 462 - Revision 0.

3. **Highways England.** *Post-Tensioned Non-Destructive Testing and Monitoring Techniques: Assessment of Available Methodologies.* 2020. *(Document appended to this challenge statement)*

Appendix A - Current PT Investigative Technologies Infographic