CHALLENGES AND SOLUTIONS FOR MANAGEMENT OF FRP USAGE IN THE UK RAIL SECTOR

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The first Fibre Reinforced Polymer (FRP) implemented to a UK Railway Bridge was in 2001, since then a number of key railway bridge projects involving FRP have seen completion; six being fully FRP bridges. Although the potential use of FRP on the infrastructure was found in 1998 due to high strength to weight ratio, stiffness and good chemical resistance, the implementation of FRP to small scale rail bridges was found to have several challenges which are faced by industry. Past research studies have predominantly focused on providing further examples of the successful usage of FRP in bridges, the benefits to whole life cycle cost in comparison to steel/timber but fail to address the challenges. In that context, the study is aimed to identify the key challenges for managing the usage of FRP in large scale in UK rail sector and provide possible solution to overcome such challenges so that dependency on traditional materials on railways bridge can be reduced and improve material sustainability aspects. This paper explores the past research and takes a view from the project delivery level. A qualitative approach was adopted to collect the views from professionals associated with clients (Network Rail), designers and contractors using questionnaire. A total of 14 professional's views were collected through questionnaire and findings outlined. From the analysis, it was found that the lack of standard design codes for FRP, basic understanding of benefits, right price and reliability are key challenges for the management of FRP use in the UK rail sector. The paper concludes that the use of FRP will be an alternate solution in UK rail sector from the material sustainability aspects if confidence of stakeholders can be improved about reliability and the practical benefits of FRP.

Keywords: FRP, bridges, whole life cost, standards, network rail, perception.

INTRODUCTION

Fibre reinforced polymer applications in the arena of bridges has seen considerable progress since the mid-1990s. The driver of this has been the marrying of the materials properties to the requirements of bridge infrastructure and the need to modernise existing structures up to 21st century loads and standards (Hollaway, 2010, p 2430). FRP offers infrastructure owners, operators and maintainers the potential for quicker installation times; the high strength-to-weight (S/W) ratio allows for reduced capacity, more readily available, cranes and lifting equipment to be used. The strength-to-weight ratio/specific strength is a material's strength (force per unit area at failure) divided by its density. This provides more scope in the scheduling and

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planning for projects. Also the durability and chemical resistance offers the potential for reduced maintenance regimes, allowing for better whole life cost (WLC) performance and ultimately cost savings (Hastak, 2000, p103). The two largest operation and maintenance management organisations of bridge structures in the UK are the Highways Agency (HA) and Network Rail (NR). Both organisations have been active in the research and development of FRP to their infrastructure, with case examples being thoroughly published in papers. Within these two sectors a pressure exists to mitigate residual impact on their networks during the undertaking of construction schemes; more so with NR, having a limited number of lines and routes. Working line side on NR infrastructure is typically restricted by maximum 48hour possessions, to main line interfaces (Canning, 2012, p3). The closure to lines and disruption to the network is a core consideration to NRs WLC modelling of schemes. With NR set to enter their next control period (CP5) and a key aim being "deliver efficiency savings of 18%" (Rail, 2013, p3); FRPs proven potential benefits to infrastructure scheme costs (Bell, 2009, p121) may be able to serve the organisations needs outside its current trail focused experiences. The paper intends to highlight the experiences of FRPs use on NR infrastructure and to understand the barriers & challenges that exist within the sector affecting the implementation of FRP incorporated bridge schemes. The findings of the paper have the intension of increasing further awareness of the materials management, particularly in application aspects, within the rail sector.

LITERATURE REVIEW

A review of current literature found three major applications with the rail sector (Figure 1).

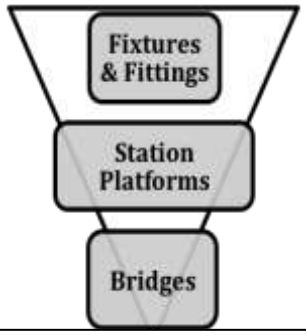

Figure 1: Hierarchy of acceptance

Bridges

Network rail own and operate some 40,000 bridges across 33, 800 km of main line railway (Bell, 2009, p119). It's for this reason why research into the bridge application of the material has been extensive. The properties of the material coupled with the requirements of bridge infrastructure makes for a theoretical match. FRP in this application, from research and case examples, is a jostling between the cost effectiveness of the material manufacture and the required resilience of the structure. From the late 90s NR has worked with a number of consultancies to build their understanding and portfolio of FRP onto its infrastructure. During this time controls such as requirements for use criteria, specifications, agreed design methods and post installation management recommendations for FRP refurbishment schemes were established (Bell, 2009, p120). NR has been driving forward its portfolio of experience with FRP bridge structures (Brinckerhoff, 2006).

Re-decking
FRP re-decking of a bridge structure is undertaken by the use of repeatable FRP cellular decking systems and whole plates. This is currently the most cost effective manner in which to manufacture and install the material (Canning, 2009, p2). Up to now the use of FRP decking systems as a form of refurbishment have seen several applications to NR bridges since 2001 (Bell, 2009, p119). Re-decking is commonly carried out to replace timber decked bridges, this form of structure is common on the infrastructure and design life is relatively low should regular maintenance not be carried out (Canning, 2012, p. 1). On the infrastructure to date the number of under bridge re-decking examples is limited; two know UK applied cases are Rubha Glas Viaduct and Calder Viaduct (Canning, 2012, pp 5-7). Due to the requirement of rail under bridges to have capacity for derailment load, FRP has to be designed with consideration to this. Over bridges have no such derailment requirement and from studies and cases carried out by the HA, NR see greater potential to this application (Bell, 2007, p28). The reduced weight of the FRP deck is of a significant benefit to dead load applied to the existing substructure; also required crane capacity could be minimised allowing for a greater scope of plant to be used (rail-mounted cranes) (Speight, 2009, p106).

Bonded plate strengthening
FRP bonded plates to bridge soffits, have seen the most prolific use on the infrastructure, over 20 examples (Bell, 2009, p119). Bonding of carbon fibre reinforced polymers (CFRP) plates to bridge soffits as a form of strengthening, the increasing of load capacity of structure has seen the most common application to date. With the controls established by NR and its partnered consultancies, successful applications have been achieved.

Whole new structures
A total six new FRP bridge rail structure found to date, for example: St Austell, Standen hey, Launder aqueduct, Bradkirk, River Leri and Dawlish. These structures consist of varying construction forms, but all are made entirely from FRP (Bell, 2009). The spans of the whole FRP rail bridge structures to-date lie around 10m; this is not a limiting factor, as greater spans are achievable. Proven examples of hybrid bridge systems involving steel beam and FRP slab arrangement can span approximately 25m (Canning, 2009for Mount Pleasant M6 over bridge.

Challenges and Barriers

First Cost ≥ WLC
Studies have outlined the possibility of FRP incorporated schemes being parallel in terms of time and cost to steel/concrete (Canning, 2009). This is based on the savings made on closures required to major infrastructure routes, and required lifting capacity in terms of initial cost, standards and experience (Figure 2). This aside, the first cost of the material is comparatively high to its counterparts (Speight, 2009, p106). This is the counterbalance to its WLC benefits. It has been said that this cost could be reduced by the grouping of a number of projects together, taking away the current bespoke nature which the manufactures work to (Bell, 2009, p123). Further to this, should standard modular bridge systems be developed a similar effect on manufactured cost would theoretically occur. This however is limited by span lengths for whole FRP bridges but not with hybrid FRP bridges (Shave, 2009, p 9).

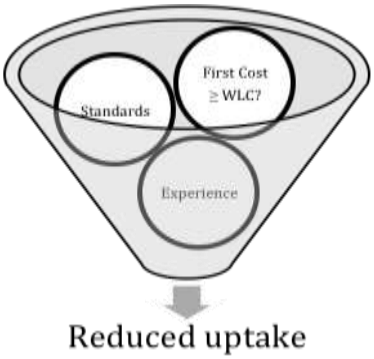

Figure 2: Challenges to uptake

Standards

Reasons for no formal design codes/standards are outlined effectively by (Farmer, 2009, p 142) "The limited use of FRP in structures; Variability of properties, depending on method of manufacture and orientation of matrix reinforcement; Insufficient compilation of project data; FRP manufacturers' unfamiliarity with construction industry standards of design and quality assurance." The lack of formal FRP design standards is at a disadvantage compared to steel/timber/concrete, which have design codes that are universally accepted and can be tested against.

Experience

High factors of safety have been applied to the schemes carried out so far, which have reduced the efficiency of designs (Hollaway, 2010, p. 2437). This suggests that the confidence in the material is a relation of this experience. Experience is seen as a barrier not limited to the design; quality control, testing and inspection and in service damage are all relevant. These factors have to be considered by NR on all its schemes and so limited experience with this presents a barrier (Bell, 2009).

METHOD

In this study, qualitative research approach was used to achieve the aims of the study. In this approach, semi-structured interview was selected as a research method for data collection because this allows for a dialogue of open exploration and a critical analysis into the subject matter. The participants in the questionnaire survey were targeted randomly from different stakeholders; such as client, designers and contractors, which are responsible for the acceleration in the use of FRP in the UK rail sector. This also allowed for a coherent comparisons and analysis of views gathered from the participants. A total of 14 responses from different stakeholders (see table 1) were gathered and used them to analyse using thematic approach to reveal the findings from the survey. The structure of the questionnaire was designed based on the key categories; such as experience, confidence, lack of standards and whole life cost. The questions were tailored to bring the responses in line with this research objectives and to analyse the perception and understanding about the foreseen barriers to confident use of FRP. The thematic approach was used to analyse the interview transcripts and the frequency of use was defined in thematic diagrams. The outline of views and opinions expressed are found under each category heading. Findings have been interoperated by the authors to analysis the meaning of the themes uncovered.

Experience

Table 1: Spread of individuals interviewed

Years' experience	6-8	9-11	12-14	15-17	18-20	>20
Network Rail	2		2			
Designers		2		2	2	1
Contractors		2		1		

FINDINGS

Confidence

Appropriate scenario
The material is not seen as a universal solution for all scenarios, each scheme undertaken is individual and to a certain degree bespoke. As initial cost is high, benefits in using FRP incorporated designs are invariably suited to a minimal array of scenarios; highly corrosive atmospheres (coastal) or sites of limited access (large plant required). This has been the driver for whole FRP/Re-decked bridge locations to date.

Bond durability/technology
The application of FRP comes with its own technique/installation methods; although it can be bolted into position, use will involve some degree of bonding and adhering. Invariably this is the area of most failures seen. The need for additional technics to be adopted in the construction process is understood as a further barrier may reduce the willingness of use.

Experienced Failures
The failures experienced are limited to the bonding/connections details and are few in number; overall this aspect has not been seen as reducing confidents in the material use. Understand between all parties involved that failures haven't stood with the material itself but with the site workmanship and/or design.

More study needed
Unlike examples outside the rail environment, road bridges over rail require standard H4A parapets which generate loads on impact that are difficult for current FRP products to restrain. The bonding and service life aspects of the material are currently under study at Southampton University, further work/research is keenly sought in this area. Fire resistant and performance under vandalism are core consideration and are yet not conclusively understood.

Correct Novel Classification
FRP use in the bridges arena is classified by NR as novel, this classification is well accepted among the individuals interviewed. Being novel means additional checking, known as a category three check, has to be undertaken on designs. This extra protection is regarded as being appropriate due to the current sensitivity of the materials reputation.

Design Code Lacking
The lack of formal design codes and how this affects FRPs confident use is discussed and expanded on in the following section; however it is worth noting it was mentioned by all levels as a direct reflection on the confidence in the materials use on the sector.

NR Internal variance
NRs infrastructure is split into routes being managed by individual asset teams; generally experience with the material is varied to only the routes where appropriate scenarios have been available and asset management teams having seen the potential

off the back of HA lead schemes (Mount Pleasant and West Mill bridges). A balanced level of understanding and awareness does not extend throughout all routes.

Prejudice, Caution and Reputation
The lack of formal design standards/codes is perceived to give an impression of still being an experimental material, also the connotation of being plastic is a stigma which sustains a prejudice in the mind-set of many engineers and is difficult to overcome. Lacking in understanding of the material allows for it to be easily dismissed.

Publishing success
The selling of success is seen as important in spreading confidence, it was noted this could be done better. The FRP champions within NR number one/two and have been the drivers of the material to-date; for wider opportunity the knowledge held by these individuals would benefit from being further publicised.

Lack of standards, the effect

Experience
A high level of experience with the material outranks any formal standards/codes, should they be produced. Classification would cease to be novel however the nature of designing with the material commands a level of experience/understanding, outside of what is currently written down. The development of standards would still leave a certain level of caution with application. Approved companies have capable/ specialised professionals which, NR is satisfied, meet the required level of experience. Should these individuals move on; NR confidence in the capabilities of the approved company to design in FRP would be compromised.

Client Approval
Due to the high risk environment of the railway, engineers are particularly conservative. FRP schemes conducted to-date has been subject to specific testing requirements monitoring performance for future schemes and approval engineer's peace of mind.

Sustains novel classification
It was said that this classification is perhaps sustained by the lack of formal standards. The novel classification may be a stigma to further use by engineers who see it as a red flag, and avoid whether the material be appropriate for their scheme or not.

Reduced design continuity
Standards would allow for correlation between designed projects. Currently it is viewed that the freedom given by the design guides means the schemes currently completed on the infrastructure have a degree of difference which is unnecessary.

Whole Life Cost (WLC)

Recent concept
FRP bridge schemes carried out to-date have been undertaken with initial time and cost being the key selling point of interest. Whole life costing attitude is set to shift in the forthcoming control period; underpinning the new asset management policies.

Initial Cost Priority
Many schemes have fallen at the wayside because the initial cost had been too high. An example included the replacement of a nine span footbridge south of Doncaster station. The structure was listed and in order to be replaced in line with this the associated costs stalled any further development. The new policies set to bring whole

life costing of projects to the forefront of considerations are based around an economic WLC. Three aspects are to be satisfied.

- Efficient - With resects to delivery
- Sustainable - Economically, costs don't accumulate over time
- Robust - Deliver the same required performance of the last CP(4)

Manufactures and high cost
Within the UK manufacturers of FRP structural products number in the range of 2-3 having limited experience in 'heavy' engineering (e.g. turbine blades). Unless a scheme has been outlined as FRP from the start by the client, project time scales have in the past caught out the manufacturer. The nature of the current production market doesn't allow for the flexibility seen in steel/concrete fabrication.

Standard designs
Currently there are 3-4 different types of common FRP decking systems for bridges. The preference of these types is scenario dependant, based on the trials to-date. The development of standard designs would theoretically allow for manufacturing costs to come down. Couple this with batching of schemes and the mass production of the units would make the investment in machinery and technology increasingly worthwhile.

ANALYSIS

Spread of data

The specific nature of the topic 'FRP in Rail', limits itself to a very narrow steam of professionals. The experience of the professionals involved in the study allows the views and options uncovered in the thematic data to justify the shallow pool of interviews undertaken.

Pockets of confidence

The view of varying degrees of confidence around NR is drawn from the nature of how the organisation is broken up into routes (Figure 3). The confident routes have a portfolio of example uses within their jurisdiction, which leaves future FRP bridge applications on the given routes, less susceptible to unnecessary prejudice or caution. The prejudice and caution is as a result of a lack of understanding of the material. An awareness of the potential benefits, limitation, past uses and success, lacks in these routes. The reasons to run with an FRP bridge scheme are not generally understood as well as the reasons against; which for inexperience engineers is a difficult aspect to overcome especially in a historically conservative rail environment. Publishing of success can only take the understanding of the material so far and will not have a dramatic effect on uptake alone. Like those routes of minimal experience, trailing the material on appropriate assets within the inexperienced routes has the potential to balance out the confidence levels within the organisation. Design considerations for fire and vandalism are areas which need further work adding to the lack in confidence to pockets of the routes and conations of being known simply as plastic need to be tackled with proven examples.

Figure 3: NR Routes (Rail, n.d.)

Standard of Experience

The argument given to the novel classification of the material and the lack of understanding means it is correct to sustain its classification, which has been suggested as intern maintaining a level of prejudice within NR. Understanding based on, experience and design guide knowledge are key to the successes of all the previous FRP schemes undertaken by NR. The current fragile reputation of the material dictates that this would have to remain the case until a formal standard/code has been created and even beyond this, in order to build a case for the material. The publishing of standards/codes would allow for an increased level of confidence to exist from the approvals aspect, as an engineer will have a credible reference to which a design can be certified against. Further too this additional level of understanding would be required; awareness, experience and knowledge are the aspect of understanding idealised for confident use.

WLC attitudes

The WLC modelling systems and policies coming though the new CP5 should make it easier for FRP to be seen as a more credible solution. The processes at which the models are used however pose a potential barrier to FRP. If knowledge and understanding of FRP lack within the local knowledge pool than it will not be used. It is fair to conclude that the power for implementation of schemes lies more with the regional route asset management than HQ, see Figure 4.

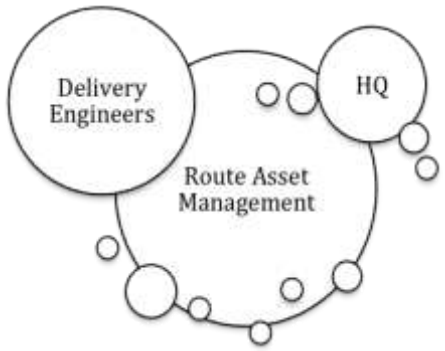

Figure 4: Power of FRP implementation

The new WLC approach underpinning the CP5 is based on an economic whole life costing. The schemes to-date that has proven a time and cost saving before WLC is

even considered are likely to be the model for which any future FRP schemes are to be based off. Proving at feasibility stage that the potential savings in man hours and equipment needed (relating to its S/W properties) fits more in line with the aims of the new strategy.

Marrying up appropriate scenario with the right price enables barriers which have formed the perception of the material as none-viable to likely fade. For this to happen, not only does the spread of understanding have to balance out as discussed, but the manufacturing of the material needs to be re-thought. For greater efficiency the batching and grouping of multiply schemes would make the production more economically feasible for the manufacturer and thus the client.

DISCUSSION

An economic WLC based system, would play to the potential benefits of using FRP on structures. The policy leans towards best WLC unless a good reason not to run is given; which for a government organisation stands to be the correct attitude towards its assets. The models run place the final decision on local knowledge and understanding which is where this has the potential to fail FRP; the spread of understanding of the material within the organisation is limited to only a handful of individuals. This may allow appropriate scenarios for FRP to be more readily overlooked. The ill balance in confidence though the different routes is based on a prejudice, lack of experience and awareness. Aspects such as fire and vandalism feature as concerns which exist and have not been fully satisfied.

Manufacturers have had a difficult time supplying the products for FRP bridge schemes in the past, having to heavily invest in machinery and technology without the forward outlook of production known. This maintains the bespoke nature of new FRP bridge schemes, intern sustaining the price and having a large impact on the efficiency aspects of the WLC modelling. This would theoretically allow for FRP to be more viable at the current manufacturing capabilities/cost.

Should standards be developed, it is foreseen this will only aid in reducing caution regarding client approval. High degree of control will remain on the individuals who are allowed to design FRP incorporated structures on the railway. The historically conservative nature of the sector ensures this. Sustaining a growth in FRP capable professional entering the profession though academic studies are needed, as should the pool of professionals capable within the sector currently retire/move on FRP will have no place.

Number of interviews undertaken was a limitation to the study as the more carried out would have increasingly added worth to the study. Additional input by individuals from Network Rail specifically the Asset Management teams would allow for a more worthwhile study as the findings raised are most relevant to this area. Time for the study has also been limited and so reduced the potential reach and exploration of the aims.

RESULTS

Enablers in Figure 5 are based on views, opinions and experienced analysed. Each represents what is needed for uptake in FRP to be confident within the sector.

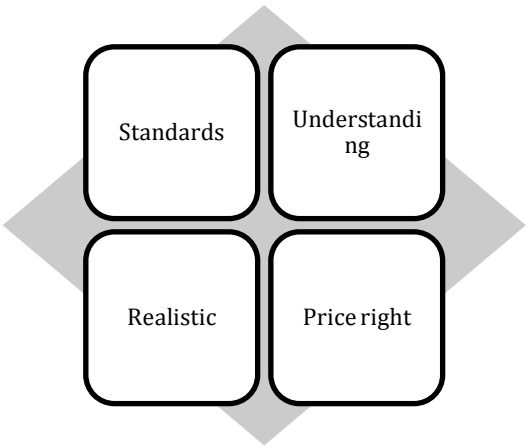

Figure 5: Matrix of enablers

Enabler, Standards

The production of formal standards/codes would only server the perceived experimental nature of the materials use; due to understanding being the overruling requirement. This said the prejudice that exists will continue to exist should formal standards/codes not be produced, despite updated design codes under production. As engineers it is built in to abide by a certified code and denying FRP this only serves as a disadvantage to its potential.

Enabler, Understanding

Having the right people with the right level of understanding enables the portfolio of FRP to grow without being plagued with failure. For this to continue Universities need to continue to include composites within their syllabus and the sector needs to actively encourage capable individuals.

Enabler, Realistic

The materials use in the bridge arena is not a universal solution. The sole benefits of FRP to WLC are not in line with the economic WLC strategy of NRs next control period. The success with schemes where savings to initial installation and time were made, are dissolvable into NRs WLC models.

Enabler, Price right

As the economic based WLC models are the way forward, outside the proven schemes. For manufactures to become more involved with the sectors need and in co-operation, set up standard designs to which can be rolled out in a generic scenario, cheaper and with greater quality control. In the interim should the price of steel/concrete accelerate, the comparable price may enable FRP to become more viable.

CONCLUSIONS

These enablers make up a collective set of requirements for FRP in the rail bridges arena to be successfully adopted confidently. Introducing formal standards would put rest to an experimental prejudice which may rest within the mind-set of cautious approval engineers. The understanding of the material is needed throughout the industry, only then will a wider uptake be seen. The capabilities of the designer are highly regard by NR, for this to be sustainable academia needs to continue to teach composites to new engineers. Also trailing of the materials use should continue with

funding made available to specifically target the routes lacking in experience. The benefits to use need to fit into the aims of NR, therefore savings to initial time and cost on projects is for the interim the most appropriate way for FRP bridge schemes to continue; until a broader portfolio is established and the WLC benefits alone are rated more by the client. Co-operation between the end client and manufacturers in the development of standard deigns would allow for batched schemes to become a realistic opportunity for FRP. Theoretically reducing the initial production costs and making a further case for being the best WLC option.

RECOMMENDATIONS

- A more extensive study into the perceptions of FRP is necessary in bridge application.
- Future study into the effectiveness of the material to withstand vandalism in urban environments is required to improve reliability of FRP.
- EU/UK Gov. funding should make available to carry out further trails on the infrastructure, preferably on routes with limited experience.
- The development of standard NR FRP Bridge designs codes is required.

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