Inspiring the bridge engineers of the future: a STEAM day collaboration between the University of Sheffield and Churcher's College

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Abstract: A small scale cable stayed bridge has been designed and fabricated as an extracurricular activity by staff and students at the University of Sheffield, for use in teaching and outreach work. The bridge has been used as the centrepiece of a bridge themed STEAM day at Churcher's College. This paper describes the design and fabrication of the bridge, as well as the STEAM day activities, in more detail and reflects on how successful the STEAM day has been in inspiring interest in the STEAM curriculum in general, and bridge building in particular.

Keywords; problem based learning, outreach, STEAM, inspiring the next generation, collaboration.

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1. INTRODUCTION

As part of their outreach programme, staff and students from the Department of Civil and Structural Engineering at the University of Sheffield have designed and fabricated a 7.2m long cable stayed footbridge, which can be used at open days, or taken out to schools, to provide aspiring bridge engineers with an insight into the profession.

In an ongoing collaboration between the University of Sheffield and Churcher's College, the footbridge has been used as the centrepiece of a STEAM day for Year 9 pupils at the school. During the day the pupils work in teams to construct the bridge and undertake a series of bridge themed activities from across the STEAM curriculum.

2. THE OUTREACH PROGRAMME

Educating sufficient students to meet the demands of the engineering sector has long been recognised as a problem, with the Engineering UK 2018 Report anticipating an annual shortfall of between 37,000 and 59,000 engineering graduates and technicians. The report goes on to state that the key to addressing future demand is to encourage young people to study STEM subjects and pursue engineering related qualifications (Engineering Council 2018). Outreach programmes, run by university engineering departments, have been shown to be an effective way of doing this (Stapleton et al 2009, Vennix et al 2018).

The aims of the outreach programme run by the Department are twofold: to encourage young people, and particularly those from underrepresented groups such as girls and ethnic minorities,

to pursue a career in civil engineering and to study for this at the University of Sheffield. Emphasis has been placed on developing practical, hands-on, activities as Vennix et al (2018) have shown these are more effective than projects or lectures in motivating pupils, whilst Colvin et al (2013) have shown that hands-on activities are particularly effective in attracting girls to civil engineering. Romkey et al (2021) have shown the effectiveness of engaging in outreach programmes in enhancing employability amongst undergraduate students and the Department encourages students to to take part in the programme, both as STEM ambassadors delivering the programme, and in developing resources for hands-on activities.

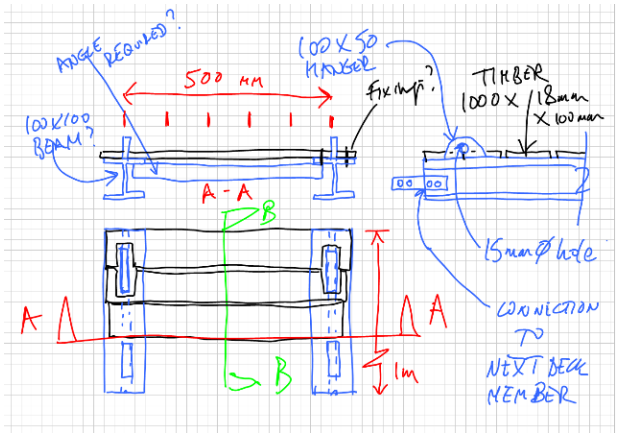
3. THE BRIDGE

The idea of producing a small scale bridge for teaching and outreach work was originally inspired by the Institution of Civil Engineers' 'Bridges to Schools' programme. The idea was developed through 'The Bridge Club', an extracurricular activity, which involved a diverse group of Y1, Y2 and Y3 students, University Teachers, Post-graduate researchers and Lab Technicians, working together over the course of an academic year to deliver the bridge.

Whilst it was pre-determined by the University Teachers that the basic structural form was to be a cable stayed bridge, all other parameters (such as overall dimensions, materials, sections, support and connection details) were left open. Given that the bridge was intended for outreach use however, it had to be easy to erect, dismantle and transport.

Concept design workshops were held at the start of the academic year, involving up to 25 student volunteers. The cohort was split into groups comprising four or five students from different years (providing excellent opportunities for peer learning), who were allocated different areas of the design to work on. In addition to the expected outcome of less knowledgeable (i.e. Y1 and Y2) students learning from more senior peers, a number of these more senior (i.e. Y3) students gained confidence from this process, and developed their existing skills in areas such as communication (Carr et al 2016). Students are able to record their participation in the Bridge Club on their Higher Education Achievement Reports to enhance their employability.

The students initially produced a range of concept design ideas, to explore both the overall structural layout and construction details. These were supported by preliminary hand calculations (Figures 1 & 2).



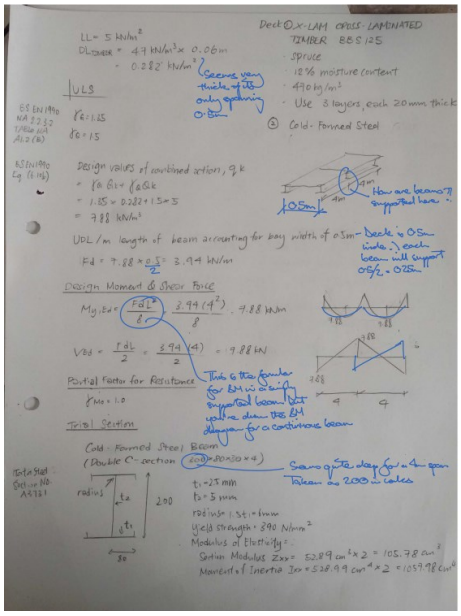


Figure 1: Concept sketches **Figure 2: Concept calculations**

Once the students had determined (and justified) their preferred solution, they carried out a detailed structural analysis using structural analysis software, learnt specifically for this project, to obtain more accurate results (taking into account effects such as cable stretch, for example) which were compared to those given by hand calculation methods, with the potential reasons behind any significant differences discussed (Figure 3).

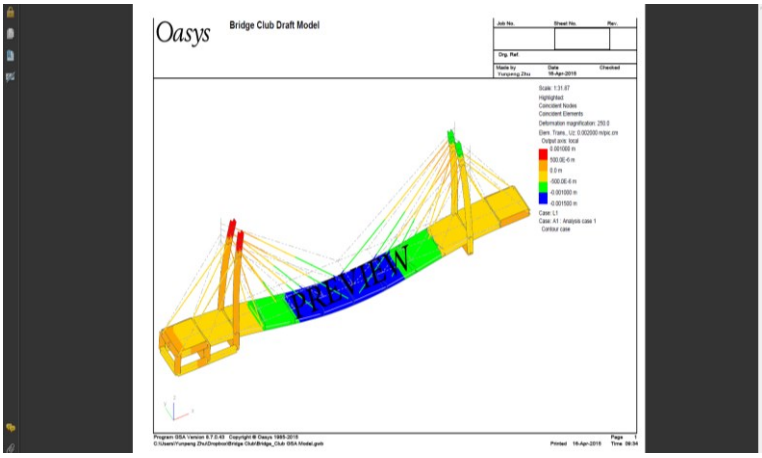


Figure 3: Sample computer analysis output

The analysis results were used to produce a full set of calculations, in accordance with the relevant design codes, to justify the proposed member sizes and connection details. CAD drawings were then produced for costing and fabrication purposes (Figure 4). Once the final design had been signed off students worked closely with the department's lab technicians to fabricate the bridge.

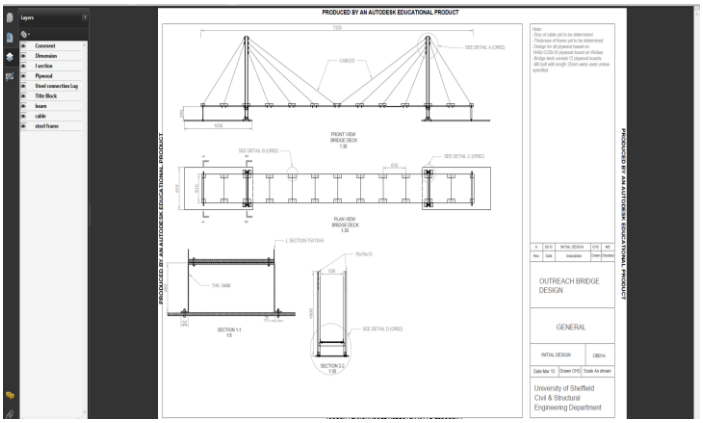


Figure 4: Sample CAD drawing

The completed bridge has a 7.2m overall span, with a main span of 4.8m, supported by stainless steel stay cables. The masts and back spans are fabricated from aluminium for ease of handling and transport. The deck is formed from plywood panels (600mm x 600mm x 18mm thick), connected with aluminium brackets. Overturning is prevented by stainless steel bars, under the backspan, acting as ballast. The bars have been sized so they can be carried by two children. The entire bridge fits into two custom made timber crates, which can be transported in the back of a Transit Van.

The bridge is now used extensively for 'hands on' teaching purposes, most notably in first and second year ‘Structural Analysis’ and ‘Structural Design’ modules, at departmental open days (Figure 5) and for outreach events. Students are encouraged to act as STEM ambassadors to help deliver outreach events. The next section describes how the bridge has been used to deliver an outreach event in an ongoing collaboration with Churcher’s College.

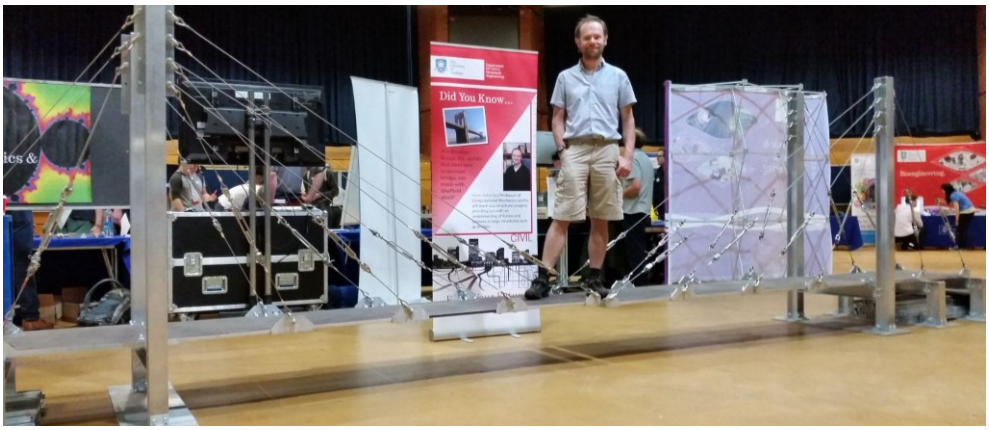


Figure 5: The completed bridge in use at an open day

4. THE CHURCHER’S COLLEGE STEAM DAY

An example of the use of the bridge model for outreach is provided by the Churcher’s College STEAM Day. Churcher’s College is a secondary and sixth form school in Petersfield, Hampshire. The model bridge formed the centrepiece of a bridge-themed STEAM day for Year 9s (13-14 year olds), intended to give the pupils a sense of the “real life” applications of their academic subjects (Figure 6). All Year 9 pupils took part, helping to achieve the goal of widening participation beyond those who might already have seen themselves as potential

engineers, working in mixed teams throughout the day on a series of activities designed to stretch their analytical, creative and teamwork skills.

Figure 6. Poster for Churcher's College STEAM Day

Pupils were divided into two groups of around eight, each group located on opposite sides of an imaginary (and crocodile infested) river and provided with half of the materials needed to construct the bridge model. The rules of the challenge were simple; construct a complete bridge in the shortest possible time, subject to time penalties if anyone stepped into the "river". The most successful teams showed an appreciation of the mechanics of the bridge itself and, crucially, excellent teamwork, for example pre-fabricating parts of the bridge "off-site" to be passed to whoever was working at the end of the bridge (Figure 7).

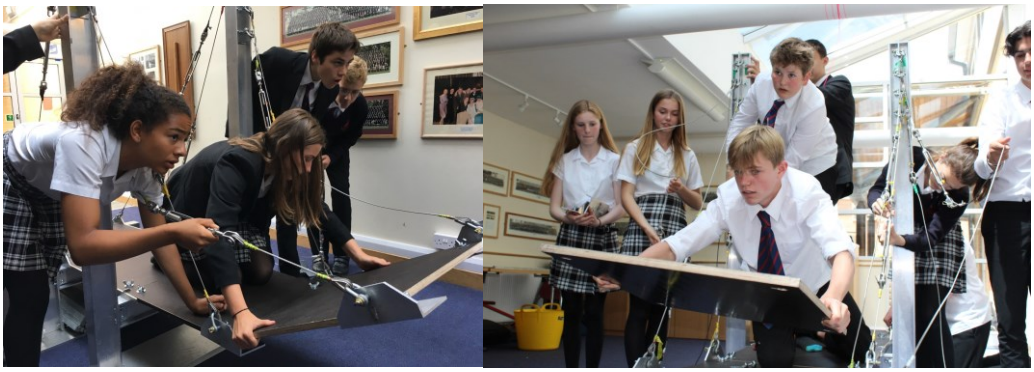


Figure 7. Pupils constructing the bridge

From a pedagogic point of view, differentiation was initially provided by the level of support provided by the supervisors and subsequently through an exercise of sketching the bridge and identifying compressive and tensile forces; an early insight into ideas the pupils would not otherwise encounter before studying A-Level Physics (Figure 8).

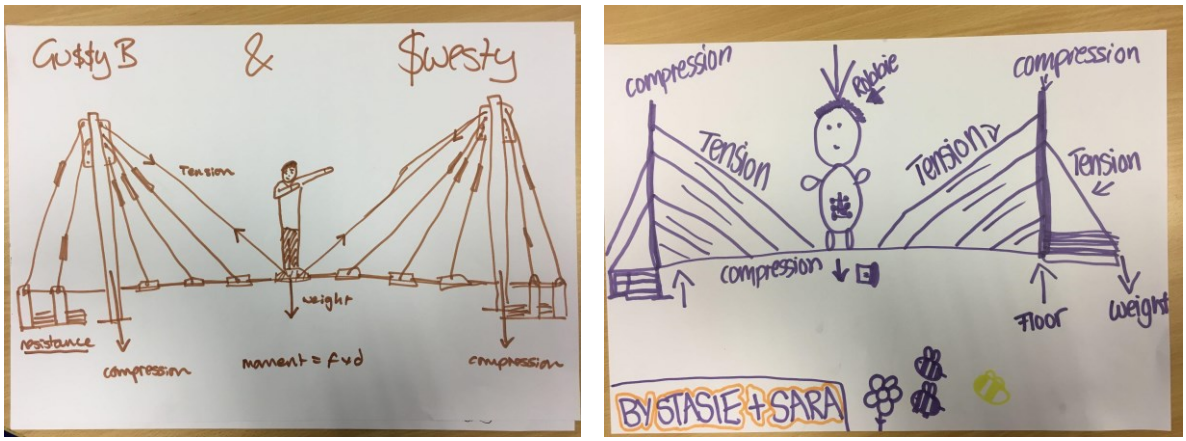


Figure 8. Sketches identifying forces in the bridge

During the course of the day, around 130 pupils completed the bridge model exercise. They also took part in activities provided by the Art Department, comparing a selection of bridge designs and then building paper architectural models (Figure 9), and the Design & Technology Department, where they designed, manufactured and load-tested small scale wooden bridges (Figure 10). Pupils also visited the Maths classrooms to work on the mathematical modelling of networks and conducted hands-on experiments exploring the concept of resonance within the Science Faculty, naturally linked to the day's theme through footage of the failure of the Tacoma Narrows bridge. Churcher's College prefers to promote "STEAM", including Art, rather than just "STEM" and bridge design provides an ideal opportunity to show pupils the importance of the aesthetic element in engineering. The multidisciplinary concept could be developed further to include ecological issues and economics.

Figure 10. Paper bridge models

Figure 11. Small scale wooden bridges

The STEAM day has proved popular with the pupils, according to their feedback, and has now been run for the benefit of four different year groups between 2017 and 2022, with some interruption due to the COVID pandemic. The STEAM day is part of a broader effort by Churcher's College to promote STEAM disciplines to both boys and girls. While it is not possible, or indeed reasonable, to isolate the impact of the STEAM day itself, it is interesting that indicators of STEAM participation have shown favourable trends over this period. For example, the proportion of pupils leaving the Sixth Form to study a STEAM related degree has increased from 31% to 52% (Figure 12). The number of pupils choosing to study A-Level Physics has also increased (from 13 for the 2016 leaving year, to 40 for the prospective 2023 leaving year), within which the proportion of girls has increased from 0% to 23% over the same period (Figure 13).

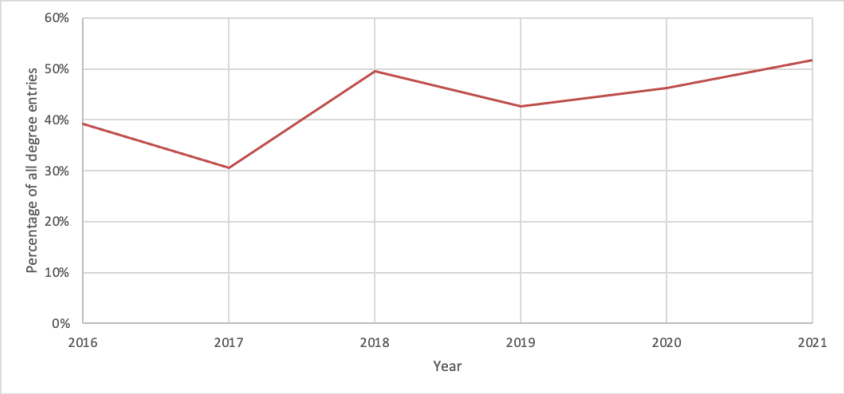


Fig 12. Churcher's College pupils choosing a STEAM-related degree by year of departure, as a percentage of all pupils choosing to study for a degree

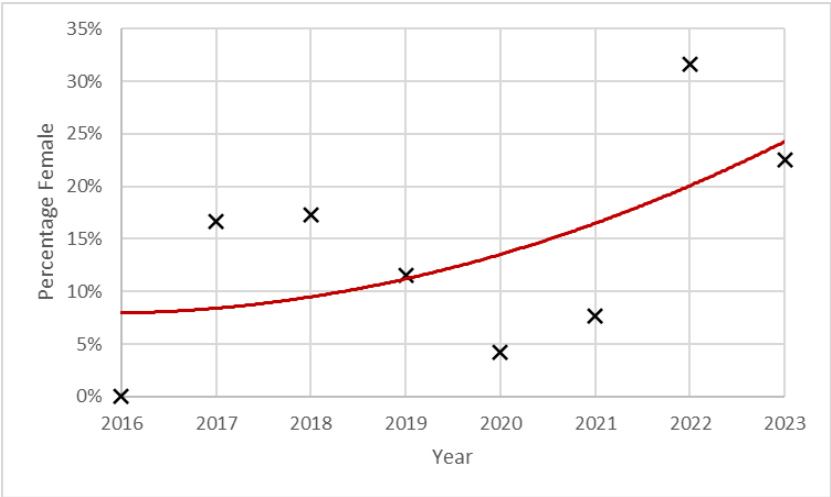


Fig 13. Female Churcher's College pupils studying A-Level Physics by year of departure, as a percentage of all pupils studying A-Level Physics

5. CONCLUSION

The design and fabrication of the bridge proved to be a very successful extracurricular activity for Civil and Structural Engineering students at The University of Sheffield, providing opportunities for peer learning, developing confidence in their structural design skills and an opportunity to be involved in all stages of a project, from concept design to construction. The ongoing collaboration with Churcher's College has shown the value of the bridge for outwork reach, both to develop teamwork skills and enthusiasm for STEAM subjects in general, and Civil and Structural Engineering in particular.

4.1 Acknowledgements

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