The rise of the concrete dragon: A bridge too far

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Gethin Roberts looks at China's astounding structural facts

I have been involved with research investigating the use of global navigation satellite systems for measuring the deflections of bridges for almost 20 years. This includes measuring the size of the movements, as well as measuring the frequencies. These are characteristic of the individual bridges, and this approach is thought to be a useful tool for structural health monitoring.

My research started on the Humber Bridge on 7 March 1996 when I placed an Ashtech ZXII RTK GPS unit on the bridge's mid-span, and gathered some data. The results showed that noticeable movements were measured. This work developed into being able to measure the frequencies, as GPS has a very precise time associated with the carrier phase and pseudorange data. At the time, the output was at a rate of 1Hz, but today receivers are capable of data output at 10Hz, 20Hz and even 100Hz. This work has expanded over the years to include such deflection monitoring of bridges including London's Millennium Bridge, the Forth Road Bridge, the Severn Suspension Bridge and the Seohae Grand Bridge in Korea — a cable stayed bridge that connects Kyeonggi-do Pyeongtaek-si Poseoung-myun Naegi-ri to Choongcheongnam-do Dangjin-gun Songak-myun Bokwoo. These surveys have expanded to having up to nine GPS/GLONASS receivers on the Severn Bridge gathering data at up to 20Hz over a continuous period of four days.

Big bridges

I am now coming to the end of my fourth year based at the University of Nottingham's campus in Ningbo, China (UNNC). Whilst I was researching my latest paper on this subject, I came across some interesting and astounding facts. When I first carried out the survey on the Humber Bridge, it was ranked as having the longest suspended span in the world at 1,410m, and had done since it opened in 1981. It was overtaken in 1998 by the Akashi Kaikyo Bridge in Japan, with a suspended span of 1,991m in length. This is still the longest single span in the world. However, the interesting facts that I came across focused on the bridges in China. Today, in the list of the top six longest suspended spans in the world, three lie in China. These are the Xihoumen Bridge near Ningbo at 1,650m long, the Runyang Bridge in the Jiangsu Province at 1,490m long, and the Nanjing Fourth Yangtze Bridge, again in Jiansu, with a main span length of 1,418m long.

Within the top 100 longest suspended spans in the world, 30 are in China. Of these 30, 23 were built this century, and of the remaining seven, only one was built before 1995, which is the Dazi Bridge built in 1984. This is a one lane suspension bridge in Dagzê, Tibet, with a main span length of 500m, a width of 4.5m, and crosses the Kyi River east of Lhasa. These facts are some of many in the expansion of infrastructure in China over a relatively short period.

Tremendous trains

China now boasts the largest network of high speed rail lines in the world. Just under ten years ago, it took some six hours

Left: A young Gethin on the Humber Bridge on the 7 March 1996.
Centre: The Dazi Suspension Bridge. ©Naomi Kong

to travel from Ningbo to Shanghai, either by car or on the train. This was partly due to the route having to go inland and back out again to go around the Hangzhou Estuary. At the time, frequent scheduled flights between Ningbo and Shanghai took 40 minutes or so. About five years ago, a new high-ish speed train line was opened along this route, whereby the D-trains (as they are known) travelled at up to 200kph, which reduced the travel time to slightly more than three hours. Also, around five years ago, the 36km Hangzhou Estuary Bridge was opened, carrying road vehicles directly over the estuary, thus reducing the travel time between Ningbo and Shanghai to three hours.

During the last handful of years, the high speed rail line network has been developed within China, typically with the tracks elevated onto viaducts. In the summer of 2013, the elevated high speed train line opened between Ningbo and Shanghai, still travelling inland around the Hangzhou Estuary. Today it is possible to travel to Shanghai from Ningbo, on the G-train, within 1 hour and 40 minutes at a speed of 300kph. It is now planned to build a second crossing over the Hangzhou Estuary to carry a future high speed train line, reducing the travel time even further to 40 minutes. Six hours travel time reduced to 40 minutes in a decade!

The typical cost of a one way first class ticket from Ningbo to Shanghai is around £25. The trains also run extremely smoothly. I pulled into a station once, and I hadn't realised we'd departed as the train was running extremely effortlessly. Earlier this year, an official from the Third Railway Survey and Design Institute Group Corporation gave a talk at the university. His discussion focused on the expanding high speed rail line across China. Some of the facts and figures he quoted are as follows:

- By 2020, the operational length of Chinese railway lines will reach 120,000km. That's enough to go around the equator three times.
- In August 2008, the first high speed rail line was opened between Beijing and Tianjin. The Beijing to Shanghai high speed rail line was opened in June 2011.
- Currently there are 11,028km of high speed rail lines in China, with a further 12,000km still under construction. In November 2013, China's high speed rail lines accounted for 50% of the world's total.
- The design of the high speed lines is different from conventional rail. The majority of the lines are elevated tracks, in effect one long bridge. Traditional rail design consists of 6-8% of the rail tracks passing over bridges. The rail line between Beijing and Tianjn consists of 88% elevated tracks or bridges, and the Beijing to Shanghai line consists of 80% elevated tracks.
- The world's longest bridge is now technically a section of the Beijing to Shanghai rail line, where one section consists of 164.8km of continuous elevated track, also called the Danyang-Kunshan Grand Bridge. In fact, 40 of the 234 bridges over 2km long in the world are in China.

In China, the high speed train network is extremely punctual. This compares to the civil air industry which has a limited operational air space, and where planes are frequently late taking off due to air traffic congestion. Flying from Ningbo to Beijing can take at least two hours, in addition to the checking-in time, travel time to and from the airports, as well as congestion delays. The high speed train from Ningbo to Beijing takes five hours. In addition to which, the train tickets are less expensive than flights. The trains travel more frequently than the planes, again making scheduling easier for the passengers.

Tall towers

Another example of the major expansion in civil engineering in China is high rise towers. 75 of the 298 tallest buildings in the world are in China, with a further 15 in Hong Kong, again illustrating the

Six hours travel time reduced to 40 minutes in a decade!

The UAV being prepared for take off and sample UAV photographs of the Ningbo campus.

The role of the engineering surveyor could be crucial in monitoring and assessing the deterioration of infrastructure over time.

growing expansion of super-structures. Currently, the world's second tallest building has just been completed in Shanghai, at 632m. This lies second behind the 829.8m tall Burj Khalifa tower in Dubai. Commission 6 of the International Federation of Surveyors (FIG) held a conference in 2012 at the Hong Kong Polytechnic University on the development and practice of monitoring high rise and tall engineering structures. Many new techniques and technologies were discussed, in particular in measuring the verticality and setting out of such tall structures. Network-RTK GPS integrated with tilt sensors is now used in real time to control the slip forming during the construction phase.

Shanghai Tower will house apartments, offices and even indoor gardens and parks with plants and trees — a true vertical city. No crops or farm animals are planned to be housed within this building, however, research is ongoing into this field. Getting fresh food from the countryside to the tens of millions of people who live in these mega-cities is a growing concern. Many such cities have population sizes greater than most European countries. Ningbo itself has around 10 million inhabitants and is classed as a medium size city!

The scope for surveyors

So what does this have to do with us surveyors, and what scope does it offer? All this expansion is occurring within a few years. The role of the engineering surveyor in terms of deformation monitoring could be crucial in order to monitor and assess the deterioration of such infrastructure over time. There is a role for the use of GNSS, total stations, photogrammetry, precise levelling, laser scanners and even the newer technologies such as ground based synthetic aperture radar (GBSAR) to monitor the deformations and dynamic deflections of infrastructure, and aid structural health monitoring. In addition to the use of technologies such as satellite based SAR and In-SAR to monitor the deformations of the ground that the entire infrastructure lies on.

There is also a role for the surveyor in monitoring and relating the movements of the ground to that of sea and river level rises, and hence help with flood prediction and prevention. This is particularly relevant as the amount of permeable ground in these expanding cities is decreasing as the infrastructure grows. The surveyor involved with such work should also be open to integrating traditional surveying techniques with those that are already established within other disciplines such as tilt sensors, accelerometers and inertial systems.

The opportunities for engineering surveying in China are very large. Today, on our campus, we can track 30+ GNSS satellites at any one time. This includes GPS, GLONASS, the Chinese BeiDou system, the four Galileo satellites, as well as the regional Japanese QZSS and MSAS, and the Indian regional navigation satellite system. Further to this, flying unmanned aerial vehicles in China is proving less problematic than in the West. Many reports have shown the benefits of flying UAVs and taking photogrammetric photographs for surveys, or even LiDAR data. [Amazon even proposed in late 2013 delivering packages using such UAVs.

The view from Gethin's window.

Flying unmanned aerial vehicles in China is proving less problematic than in the West.

However, in June 2014 it was reported that the regulations flying such devices in the USA deemed this approach too dangerous.]

In May of this year, the Ningbo Bureau of Surveying, Mapping and Geo-information flew a quad-copter over our campus in China, taking digital SLR photographs from an altitude of 180m. The quad-copter was in autopilot mode, following a pre-planned track, controlled by GPS. Watching this type of technology working for real was truly amazing. The end results are photogrammetric images, with a 5cm pixel resolution. This is part of the expanding suite of equipment and data-sets that can be available to undergraduates.

The list of advances goes on, as does the expansion itself. Millions of people are moving into the cities to work, which is evident when everyone 'goes home' for the Chinese new year — when tens of millions of people travel across the country during a few days. Many parts of China are changing at a dramatic rate, and it is truly inspiring to see it all happen. Even on our campus, we have more major developments. Currently there are four new structures being erected to take into account the expansion of the student number from the current 6,000 to 8,000.

The photograph of the view out of my office window (and it has been a while since we've seen the mountains so clearly) shows the blue and red roofed buildings of workers' accommodation — typically migrant workers from all over China. All construction work will have similar dormitories as this located nearby. It reminds me of the TV programme from the 1980s, *Auf Wiedersehen Pet*. There must be an opportunity in China for a similar Chinese version of this show, *Zàijiàn-pet?*

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More details about the FIG conference on tall buildings can be found at www.fig.net