Technologies for Relocating Buildings

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Having been awarded a Winston Churchill Memorial Trust Fellowship in 2006 to investigate different approaches to relocating buildings, I opted to visit three countries – Norway, USA and China. This article focuses on China (visited 8th – 22nd October 2007).[1]

In a culture where *Feng Shui* has dictated the careful siting of structures, one might have thought that in China, buildings were seen as immutable and rooted to the spot. And yet timber buildings have been on the move there for a long time. The Linggu Temple on Zijin Mountain on the outskirts of Nanjing was moved in the late C14th because it was 'too close' to the imperial palace. The enormous Bell Tower in the centre of Xi'an, 36m. high and first built in 1384, was re-located to its current site in 1582, mirroring the shift of the town centre. The Sengjia Pagoda in Zhenjiang, Jiangsu Province was moved to its present spot on top of Dingshi Hill during the Ming Dynasty (1627-44), having been built 300 years previously.[2] Exactly how these moves were achieved is not recorded, but in the third case we know that no precise drawings were made of the pagoda when it was dismantled, and consequently the rebuilding was more fanciful reconstruction than faithful restoration.

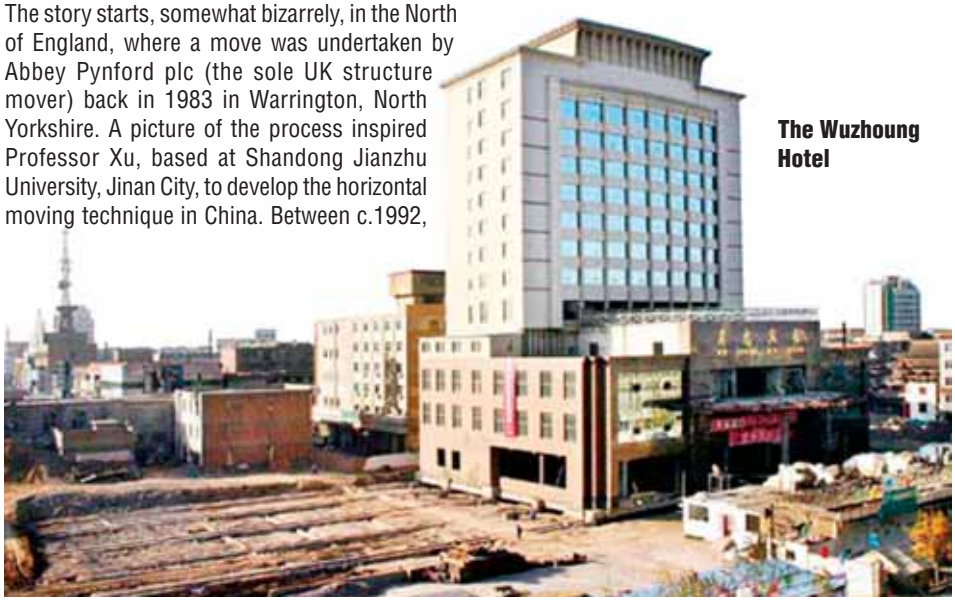
15-story building, Shandong Province

One of the main outcomes of the Fellowship Visits has been the recognition that in all three countries visited, buildings have been moved much more frequently in the past than has previously been thought. But whereas wholescale structural moving has probably been practised alongside dismantling since the first generation of buildings appeared in both the USA and Norway, China would appear to be the 'baby' of the family in this respect. I did pick up some hints that the country may once have been an innovator in this field (as we tend to forget it had been in printing, weaponry etc.) It is difficult not to view the Terracotta Army (or rather the soldiers the clay figures represent) as anything but a vast phalanx of labour capable of moving objects of any size or shape around the newly-founded country. And in the Forbidden City, imposing stairways carved from single vast blocks of stone were reputedly manhandled into Beijing using skids and ice. But in the absence (as yet) of any firm documentary evidence, China's participation in the structural moving industry otherwise appears to be traceable no further back than 1992.

The story starts, somewhat bizarrely, in the North of England, where a move was undertaken by Abbey Pynford plc (the sole UK structure mover) back in 1983 in Warrington, North Yorkshire. A picture of the process inspired Professor Xu, based at Shandong Jianzhu University, Jinan City, to develop the horizontal moving technique in China. Between c.1992, when the principle was first applied and 1998, Professor Xu estimated that more than 300 houses and buildings were moved in China.[3]

Now, in the space of less than 15 years, structural moving (or 'integral moving' or 'building shift' as the Chinese refer to it) has blossomed dramatically. The number of entrants into the industry has grown exponentially with companies now operating in all the main regions of China. (See Appendix.)

Projects have only got bigger and more ambitious. The first building moved in1992 was 4 storeys high, by 1995, 6 storeys was achieved and by 2006,15 storeys. The title for the heaviest structure moved as recorded by the Guinness Book of Records has now passed from the USA to China: the Fu Gang Building at West Bank Road, Wuzhou, Guanxi Province which was 34m tall and weighed 15,140 metric tons was moved 35.62 metres over eleven days in 2004 by the Guangzhou Luban Corporation.[4] Records are only there to be broken. Only a year later, the Wuzhoung hotel was shifted by Evolution, one of the leading structural movers based in Shanghai; it weighed 20,000 tons and had a floor area of 12700 m^2.[5]



The Wuzhoung Hotel

Recently, Professor Xu's team moved a 15-storey structure weighing 35,000 tons a total of 72 metres. There is now the prospect of a building weighing 130,000 tons, 120 metres high being moved in 2008. Structural moving may therefore be young in China, but it is by no means still in its infancy. Indeed, it is precisely at that stage where its 'youthful' enthusiasm invests it with an engaging 'can-do' attitude when presented with the challenge of tackling these monstrously large projects.

I would identify ten key elements that characterise the structural moving industry in China.

1) The buildings moved in China fall mainly into two main categories; either large concrete framed structures or complex masonry or mixed masonry and timber-framed structures that are historically protected. Concrete has been the preferred structural material for construction work in China throughout most of the C20th; steel has only recently made an appearance in the frantic bid to erect the tallest skyscrapers.

China cannot claim its record in cultural preservation has always been praiseworthy, but in the past ten years a system of graded protection has evolved and there are now 770 sites under state protection, 7,000 under provincial protection, and over 60,000 under municipal and 'prefectural' protection. Set aside for historic preservation in Shanghai's 1999-2020 master plan are 398 buildings and 11 zones (approximately 1,385 hectares).[6] However, 'listing' does not necessarily root a building to its original context. The Shanghai code doesn't make it clear, for example, what can and cannot be done to buildings determined to be 'historic'. Consequently, a pragmatic approach is often taken to move protected structures out of the path of high-rise development.

2) Most structural moves are triggered because of government as opposed to private initiatives. The massive housing schemes and infrastructure improvements currently being rolled out inevitably encounter obstacles that are 'in the way' of development. For example, No 5, Office Building of Xinxiang Water Company, a five-storey, concrete framed structure with a floor area of 1729m2 and weighing 3600 tons, had to be moved a distance of 7 metres in 2002 to clear the path for a new road.

The 15-storey building recently moved by Professor Xu's team in Shandong Province housed government offices; remarkably, it had only been standing three years before the tortuous and rapidly evolving urbanization programme discovered it was also slap in the path of a new road. Similarly, government strategies dictate the destiny of historic structures in so far as the legislation requires urban authorities to protect them. Structural moving companies consequently vie for recognition amongst the relevant government officials to win contracts.[7]

3) Because of the pace of development, the focus of the structural moving industry is in these rapidly growing urban areas. The state's role in owning and developing land means there are few small, individual detached buildings in the cities (except of course, some historic protected structures). The underlying design approach to residential, commercial or industrial construction tends to be similar, favouring the construction of architecturally monolithic blocks using mass concrete.

4) The mass and density of these concrete-framed buildings lend themselves to short distance moves. The first move in 1992 was indeed very short – only 8 metres - but in 1995 a move of 68.37 metres had been accomplished and by 1997 the moving distance had stretched to 196 metres. Even so, the Chinese structural mover's inventory does not feature wheeled vehicles or dollies as it would do in the U.S., or cranes and rigging as used in Scandinavia.

5) Instead, their equipment is tailored to carrying out short, transverse shifts, following a methodology universally adopted by all participants in the Chinese structural moving industry. The key design feature involves excavating between the building and the destination site and filling a series of shuttered beds with concrete. These beds act as a total running foundation to support the mass of the building as it moves to its new site.

The type of bed constructed is related to the methodology adopted for shifting the building. If the intention is to undermine the existing building and sever it from its foundations in situ, a series of twin tracks will be required.[8] These have to be constructed each side of the existing piles or foundations because they must sit directly beneath the upper roll beams, which act as clamps each side of the existing building support system.

Alternatively, if the building is being jacked up, the construction of the bed can echo the design of the upper roll surface; this will depend on the existing foundation system but the most common solution is to construct a concrete 'tray' that is inserted under the building to carry it.[9] Consequently, such beds will tend to have a series of individual rails rather than adjacent twin beds.

Concrete beds:

(left) Twin rails, 15-story building, Shandong

(below) Single rails, Concert Hall, Shanghai

If the structure is concrete framed, the upper roll beams are created by pouring concrete over pre-constructed cages of reinforcing rods; these are stitched into the side of the columns using reinforcing rods inserted into holes drilled into the original concrete and glued in place with a strong resin.

Preparing the column.

Formwork for columns.

Column prior to cutting with rails cast each side.

Lattice to strengthen between joints.

If the building has solid masonry walls, the roll beams are clamped using steel rods drilled through the entire wall. The resulting cast beams sandwich the existing load bearing walls or columns.

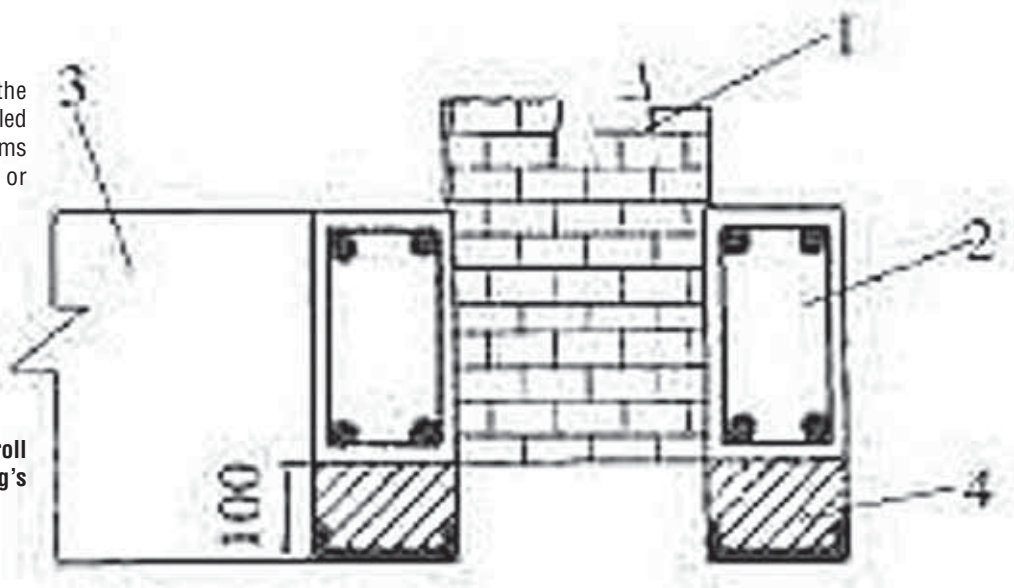


Diagram illustrating method of clamping roll beams to masonry wall, Liu Changsheng's residence, Shanghai)

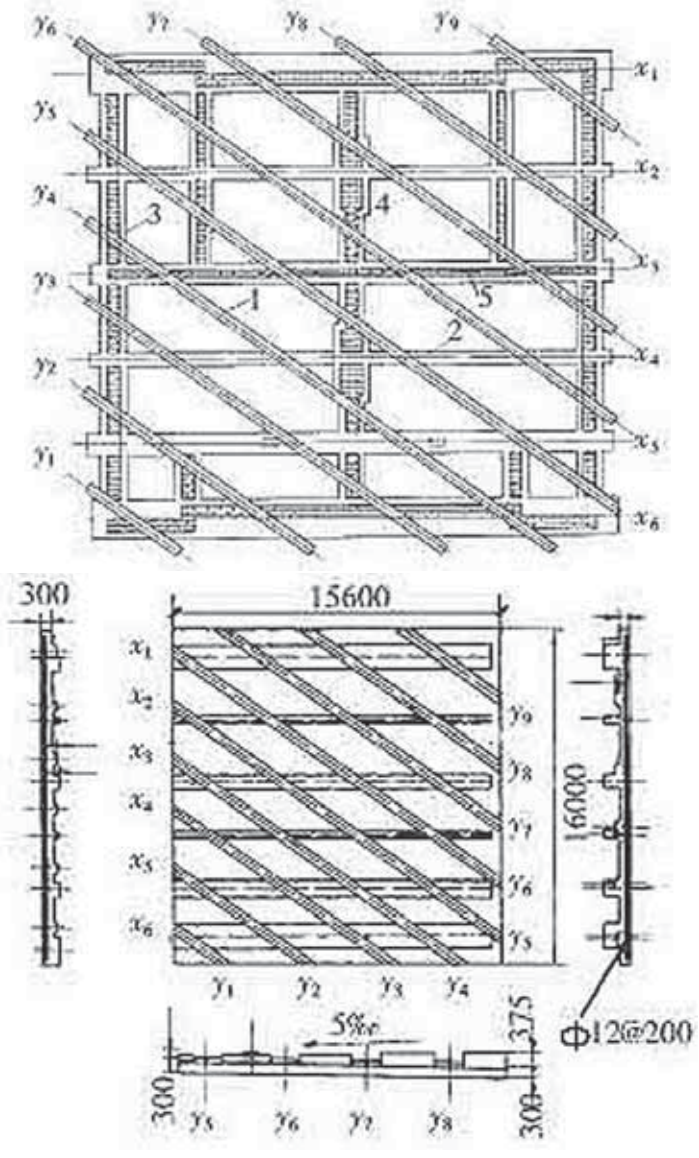
Early moves in China involved short shifts in a single direction. As confidence with skills and technologies grew, the beds were adapted to accommodate buildings with complex floor plans – hexagonal, irregular or curvilinear, for example. Changes of direction were also experimented with. The Dalian Jiuding was moved in 1999 as a joint project by the Liansheng Construction Group of Shanghai and the Huaxi Group of Benxi. A concrete and brick composite 6-storey structure, it measured 50 metres x 11 metres and weighed 5000 tons. It was first shifted to the west by 58 metres - along the axis of the building - then moved north 4.655 metres, the occupants remaining in the building throughout the shift.

This type of move may require the building at each interchange to be lifted by hydraulic jacks so that the rollers can be removed and a new set installed between the roll beams. To overcome this, more elegant solutions have been designed using diagonal or oblique angled beds, eliminating the need for point turns.

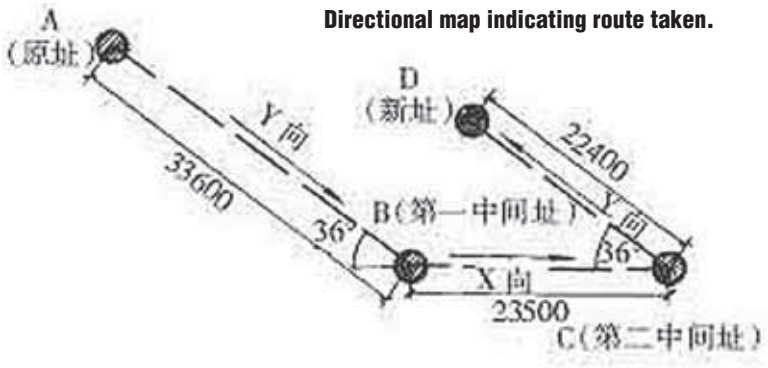
Another modification that has been introduced is that by inclining the roll beds, buildings could also be raised or lowered over the course of the shift to accommodate new plot levels. When Liu Changsheng's former Residence, a four-storey structure built in 1916 and located at No 81, Yuyuan Road, Huangpu District, in Shanghai was moved in 2002, it was the first project in China to employ an inclined slope, raising the building 0.45 metres during its transverse shift of 79.5 metres.

Liu Changsheng's former residence

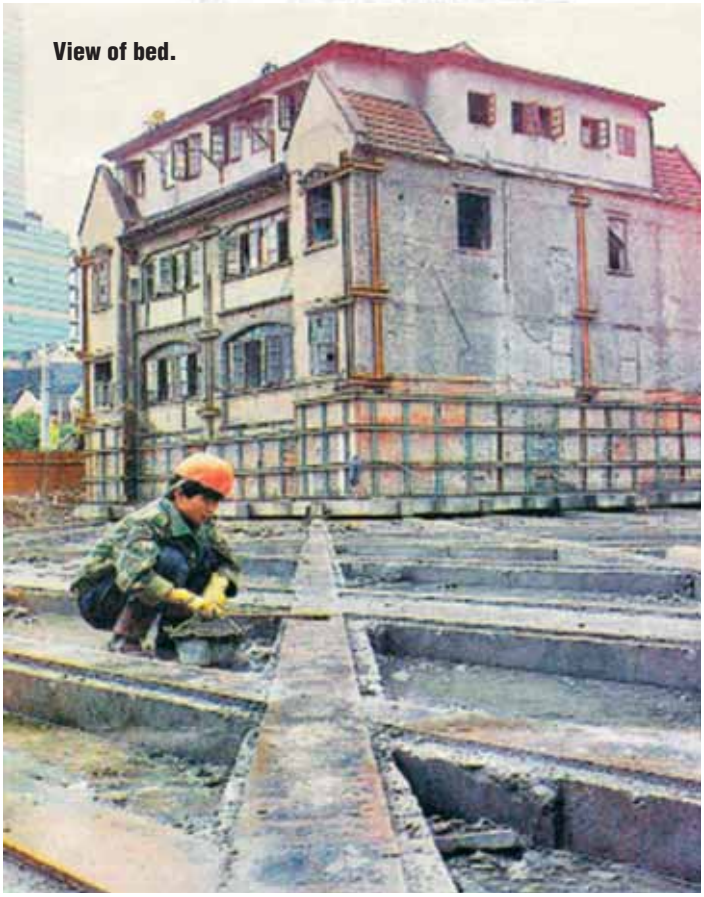
Diagrams to illustrate design of the support system.



Directional map indicating route taken.



View of bed.



The structure being moved.

The design of the beds for this project also allowed the building to be rotated twice so as to overcome irregularities in the plot orientation.

When this project was first considered in 2002, 'the original plan was to....

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Use of rollers.

Yanghang Restaurant, Jinan