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Lectio doctoralis

Innovation and Tradition in the Design and Site Management of Tall Buildings in Reinforced Concrete

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Abstract. The design and site management of a high-rise reinforced concrete building set in a highly urbanised context requires specific operational and construction strategies. In this lecture I review my professional experience and illustrate some original technical solutions that the Newway Company has developed over the last decades in the construction of reinforced concrete skyscrapers in North America.

Key words. Tall buildings in reinforced concrete, project and site management, Technological innovation.

1. Introduction. Esteemed Rector, Director of the Polytechnic Department of Architecture and Engineering, Professors and Staff of the University of Friuli, it is with great joy and a profound sense of gratitude that I stand to present to you my *lectio doctoralis*, focused on my work experience on large building construction sites.

The construction of high-rise reinforced concrete buildings in an urban context, contrary to what one is led to believe, takes place according to far from established and classical canons (Ali, Moon 2018). As a consequence, design and site management have also reached levels of increasing complexity. In fact, each work is unique, its construction making history and presenting its own set of problems. Such problems very often require original and innovative operational and construction strategies to succeed in an extremely competitive sector, by reducing execution times and costs and, simultaneously, maintaining a high final product quality and ensuring safety in the work environment.

My chosen profession as a builder leads me every day to make decisions on building sites or to choose construction technologies that can change, even radically, the fate and success of the original project. I base these decisions and choices partly on my own experience and on the technical knowledge accumulated over time, and partly on original ideas and technological innovation, where this is necessary and possible. Innovation and tradition: to me these two words complement each other, and I wanted to include them as pivotal elements in my lecture today.

In my talk, I will focus on aspects related to the design and site management for the construction of tall buildings, or skyscrapers, in reinforced concrete. I will briefly review some features of the technology used in the construction of skyscrapers, discussing the main criticalities encountered and the solutions offered by modern knowledge in the field. Subsequently, I will illustrate some innovative technological solutions that the Newway Company has developed in recent years in the construction of skyscrapers in North America. Finally, I will close my lecture with some reflections on the lessons learned from my experience as a builder.

2. The main technological issues.

The management and design of the construction site for a skyscraper built in a modern metropolis are subject to numerous constraints of a technical, technological and economic nature. Among these, the connection of the construction process to the surrounding urban layout and the city's road network plays a very important role. Other decisive elements are the execution times and quality of the final product, achieved in a way that respects the safety of the working environment. Finally, the evaluation of economic aspects, centred above all on the impact of personnel costs and the execution of the work, is another fundamental element in setting up the work site.

Identifying an optimal solution that addresses and responds to these problems necessarily involves the adoption of, very often innovative and original, targeted technological and constructive solutions, dictated by practical needs (Ali 2001). Among these, I would like to mention what are currently considered the basic technological and constructive issues:

- the development of efficient concrete formwork systems;
- the packaging and handling of concrete for large-volume, high-rise castings;
- the handling of materials on site with elevating mechanical arms (cranes).

The first half of the 20th century saw considerable technological progress on the issues listed above, but these remain the focus of attention even today. This is not surprising, as the technological solutions adopted have a significant impact on the timing and cost of construction.

Let us consider the concrete formwork system. Traditionally, the formwork was made of wood. As technology has advanced, formworks are now made by combining various materials, including wood, steel, aluminium and, more recently, fibreglass and plastics. An essential requirement in the construction of a tall building is the continuous reuse of formworks, as a much larger volume of concrete has to be poured than in buildings of ordinary height.

The need to modify the formwork according to different construction requirements has led to the definition of different formwork types over the years. The three main ones are briefly discussed below.

Flying forms, or flying formworks, offer high mobility and rapid installation for constructions with regular floor plans or repetitive structures. The system is therefore particularly suitable for horizontal floor plates in tall buildings. The fully assembled units can be manoeuvred quickly on site. Once the cast concrete has reached a suitable degree of maturity, the formwork is removed, cleaned and moved quickly or, as the English terminology suggests, “flown” to the next level of the building by means of a crane to be reused on the next level up (Fig. 1 and Fig. 2).

Slipforms are a method of construction in which concrete is poured into a rigid mould in a slow, continuous movement. The rigid mould is gradually moved upwards by a system of jacks at a controlled speed until it reaches the required height. The formwork rises continuously, at a rate of about 300 millimetres per hour, supporting itself on the core or septum and not relying on additional external supports, other parts of the building or permanent works. The height of the formwork is designed in such a way that, while the upper part of the formwork is filled with concrete in a fluid state, the lower layer of concrete poured earlier has already reached a sufficiently solid consistency. Assembly of the formwork can only commence when the bases of the structure are correctly arranged and the wall starter is aligned. The hydraulic jacks are connected to rigid metal crossbeams that support the formwork for simultaneous upward movement. The height achieved in each section varies from 1.10 to 1.50 metres. The method is particularly suitable for the construction of insulated partitions or walls of resistant reinforced concrete cores, which house lifts or stairwells in tall buildings. A limitation of this technological solution is the need to work with buildings whose vertical structure must remain unchanged in height.

In the jump forms, or self-climbing formwork system, the formwork has its own lifting mechanism and is supported on the preceding concrete casting (Fig. 3 and Fig. 4). This is often described as a climbing formwork and is typically best suited for pouring vertical concrete elements in high-rise buildings. It is a very efficient system, designed to increase the speed and productivity of the construction site by minimising labour and lead times. In addition, speed can be further increased through careful planning of the construction process. The use of a climbing formwork system considerably reduces the time the cranes are in use, allowing them to be used for other tasks. In some cases, this solution can even reduce

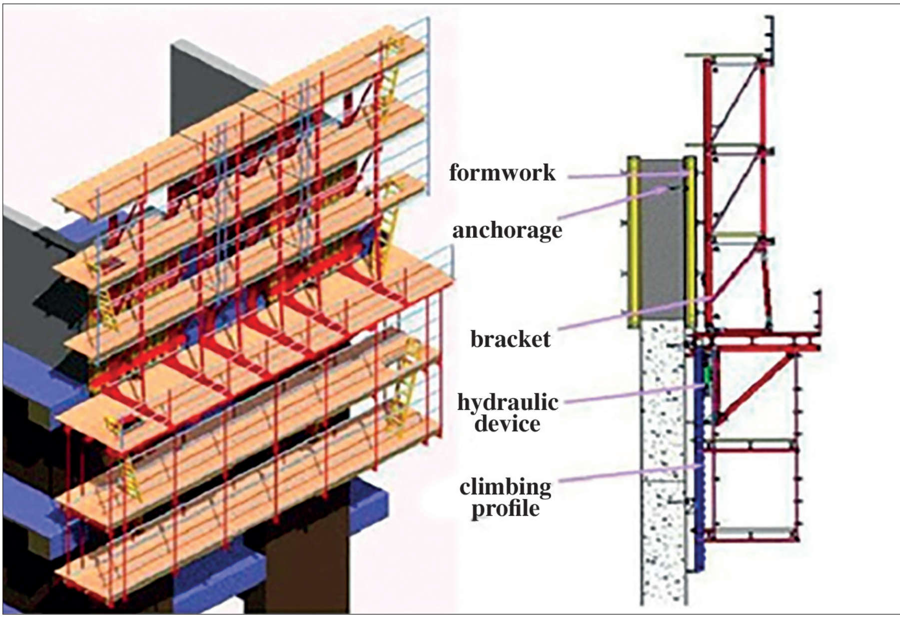

Figure 1. *Flying forms* system: (a) detail of anchorage in vertical section.

Figure 2. *Flying forms* system: b) overall view.

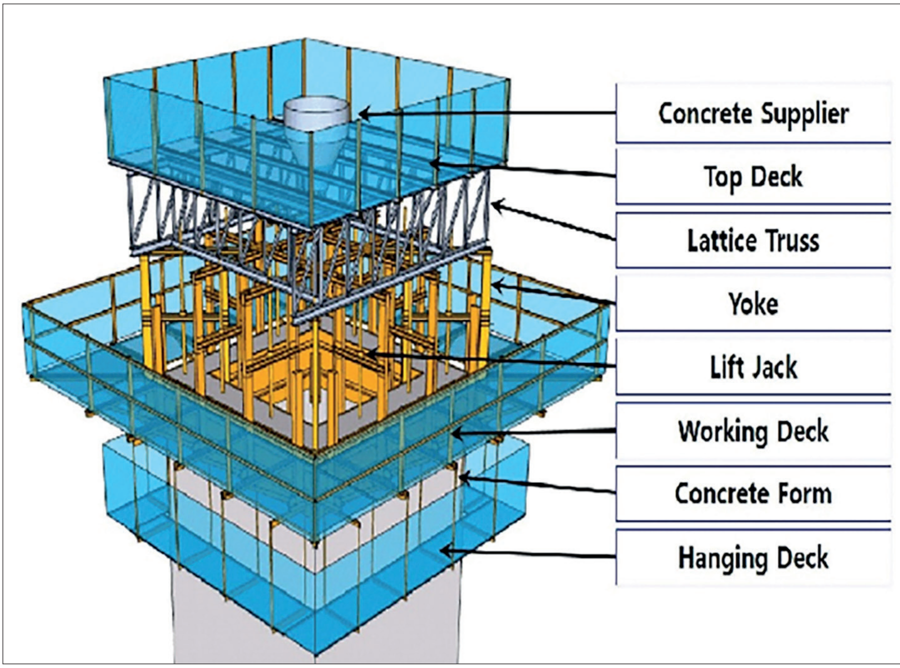

Figure 3. *Jump forms* system: (a) schematic diagram of operation.

the total number of cranes needed on site. The formwork is independently supported, so the walls of the box cores can be completed before the rest of the building structure. This can improve the stability of the structure during its construction. The self-climbing formwork system is easy to clean and highly reusable, and provides for rather low material waste. Finally, bearing in mind that safety is always a primary consideration on construction sites, the system provides for protective railings and ladders integrated directly into the units of the formwork systems, as well as automatic full-fall braking devices. The reduced use of scaffolding and

Figure 4. *Jump forms* system: (b) overall view of a septum's formwork.

temporary working platforms leads to less congestion on the construction site.

I will now turn briefly to the subject of concrete handling and pouring. Up until the 1940s, the pouring and handling of concrete within the yards of tall buildings or large constructions had been a major problem. The technology remained in an early and stagnant state until the 1960s. Then came the advent of hydraulically-driven controlled pumping systems, which fostered the development of a radically new technological landscape of tall concrete buildings. In recent years, concrete pumping techniques have undergone significant new technological improvements, dictated also by advances in knowledge of the behaviour of concrete. In fact, it is well known that pumping capacity depends on the plastic and workability properties of the concrete as well as on the elements used to transport the product up to the desired level. In the case of significant heights, such as those reached by skyscrapers, a pumping unit operating at considerable pressure is needed.

One technology that can be relied on in such cases is the so-called Concrete Pump - Self Climbing. The concrete is transferred using a static, diesel-powered pumping system by means of a fixed 125 mm diameter pipe to the folding placing boom. The boom in turn is mounted on a steel column which can reach a height of 20 metres. The column is supported by a very rigid metal base frame or is directly anchored to the building structures. The pump is capable of climbing, scaling the building as the construction is completed in height. Positioning the concrete pumping system in this way is faster than using a dedicated crane on site for this role.

Regarding the third point – the use of climbing cranes – I will shortly refer to an original solution that we have used in the construction of several skyscrapers.

3. Some original construction solutions. After this brief review of the main technological issues involved in the construction of a reinforced concrete skyscraper, I would like to describe some innovative solutions introduced by the NewWay Company. And I will do this by taking as reference two skyscrapers that we have built in recent years: The Bow and the Shangri-La Hotel. This will also give me the opportunity to highlight other site design choices that have proved decisive in the successful completion of a number of buildings.

The Bow is a skyscraper, 236 metres above ground, that was built in Calgary, Canada. It comprises 58 stories in elevation and houses the offices of Canadian energy provider, EnCana Corporation. Construction began in 2008 and was completed in 2012. The tower, designed by Norman Foster, is one of the tallest in North America.

A number of difficult issues had to be addressed during the construction of this building. Firstly, the project had a special clause imposed by the Calgary City Council, prohibiting the building site's interference with the traditional American Indian parade held at the famous Calgary Stampede rodeo. The entire construction site was divided by a road that had to be demolished and rebuilt six stories below grade in time for the parade. Thanks to an efficient organisation of work, the road was completed three weeks ahead of schedule, and even received a commendation from the City Council.

The Bow went down in the history of large reinforced concrete constructions for the casting of the foundation system. This was carried out with a continuous casting of concrete which was the largest in Canada and the third largest in the world. 13,900 cubic metres of concrete were poured in just 39 hours, using 1,584 concrete mixers and 11 pumps (Fig. 5 and Fig. 6).

The choice of formwork system also posed constructional challenges, in that it needed to meet the following requirements: very tight tolerances for the exposed concrete surfaces; repeated and prolonged reuse of the formwork panels to ensure sustainable site operations; the development of ad hoc formwork handling systems, given the unavailability of cranes or lifting equipment on site. In the end, the choice fell on the innovative PourForm-107 system, which proved to be the most effective and convenient, also in terms of rigidity, strength and stability during site operations.

The Shangri-La Hotel is a 197-meter skyscraper built in Vancouver, Canada. It includes 62 floors in elevation and 7 floors underground. It is the tallest tower in both the city of Vancouver and the province of British Columbia. Work began in 2006 and was completed in 2008. The load-bearing structure is in reinforced concrete, and the use is partly residential and partly hotel.

Even during the construction of this building, important and considered choices had to be made regarding the best solutions to adopt.

The choice of formwork system for the concrete works was a determining factor. The system involved the development of a formwork handling technique, with the capacity to build 1 floor in 5 days (about 920 square metres of slab). In addition, the system was highly sustainable thanks to the re-use of the formwork panels up to 30-35 times, and made use of fibreglass formworks in building the curved walls of the building's central concrete core.

Due to the excessive number of constraints with the adjacent building, the original construction solution involved an internal climbing crane, a traditional solution often used in tall buildings of similar complexity. This decision naturally had a strong impact on the timing of the work, as it required the availability of 16 free floors for the activities of dismantling the crane's scaffolding structures. This meant that the floors below the crane could not be completed until the crane had been dismantled and moved to higher floors for the continuation of construction. When planning the site work, NewWay proposed an innovative engineering solution that allowed the crane to

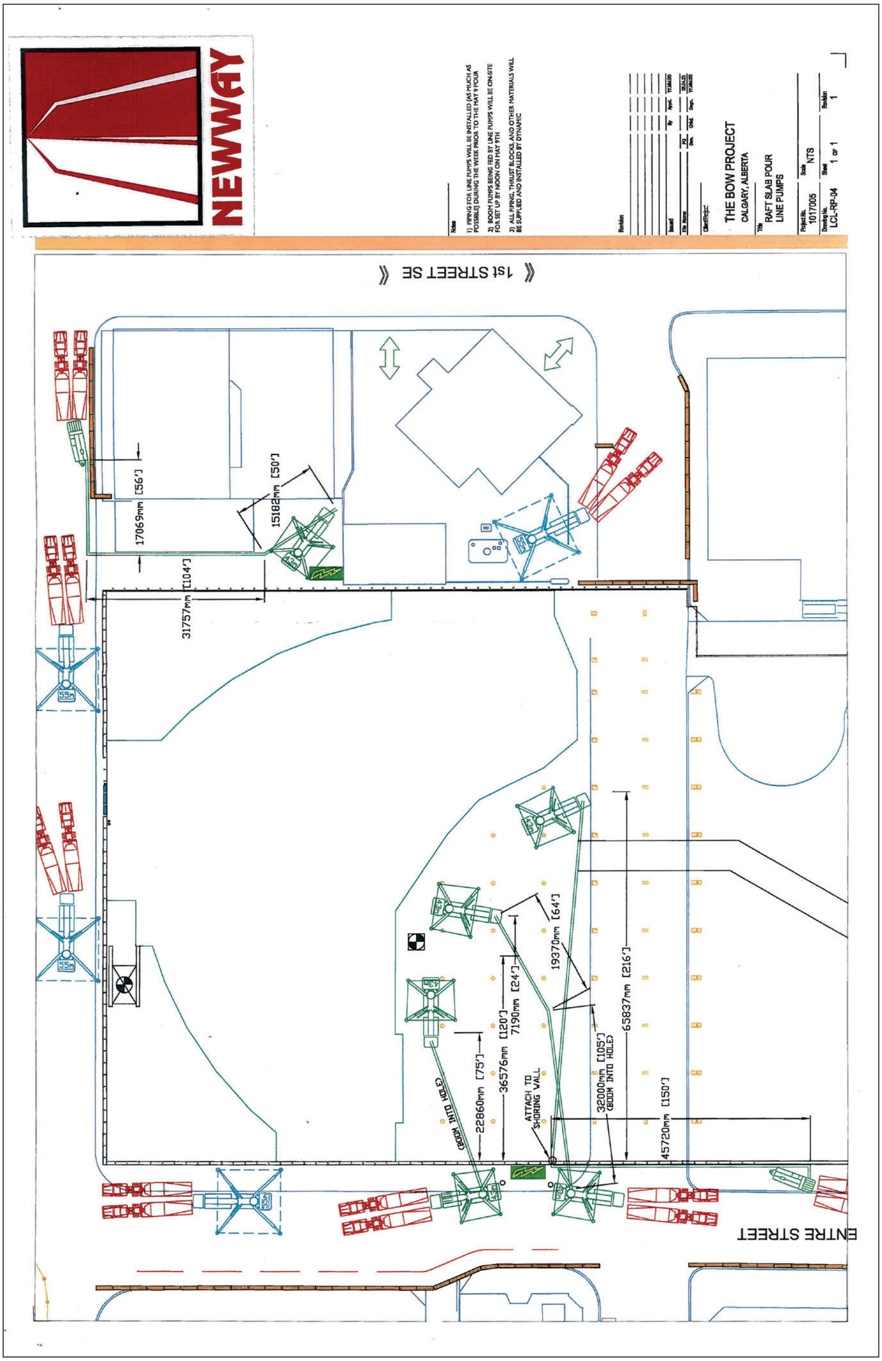

Figure 5. Schematic diagram of the layout of the concrete distribution and pouring facilities in The Bow high-rise (Calgary, Alberta, 2008-2012): location of the plants.

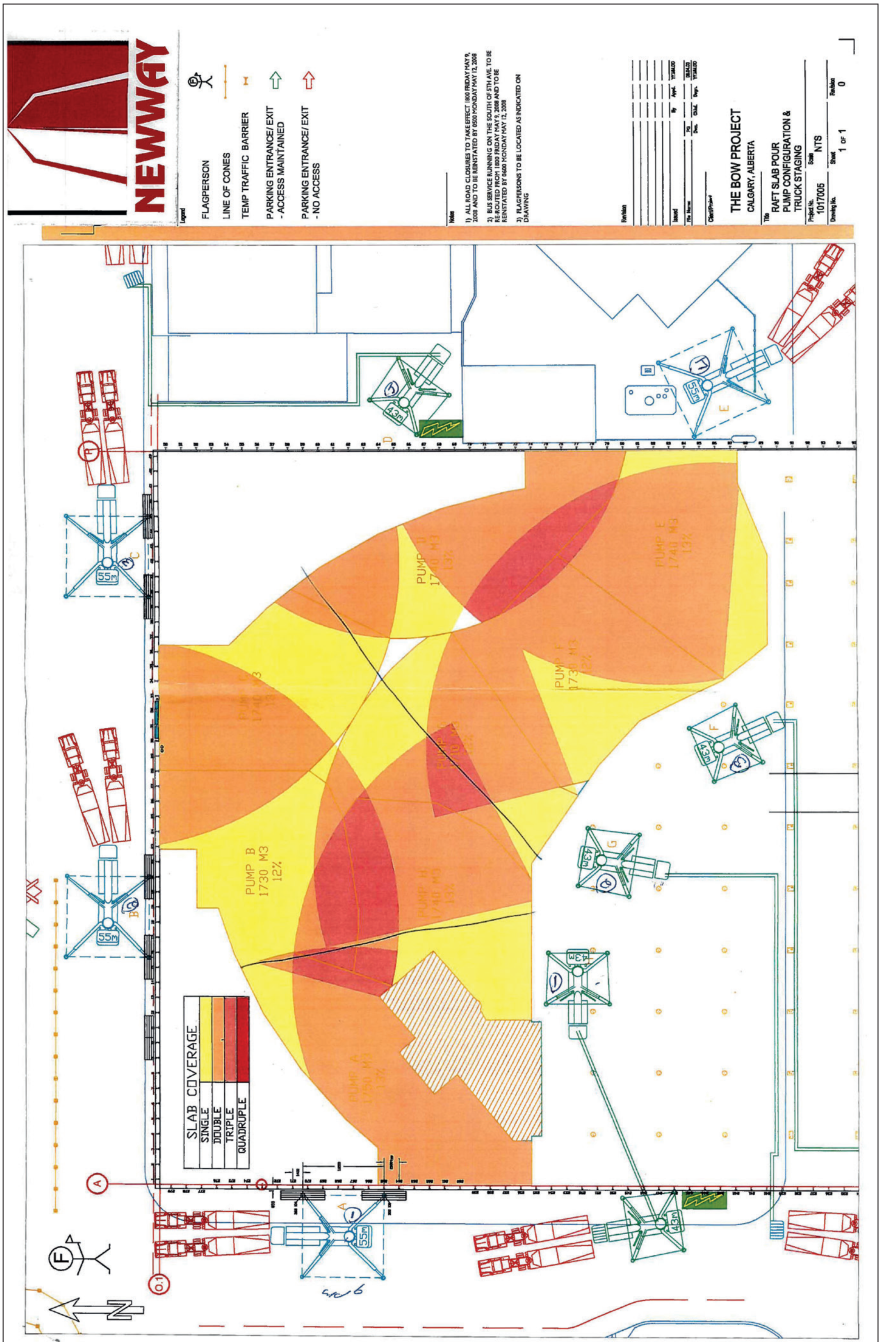

Figure 6. Schematic diagram of the layout of the concrete distribution and pouring facilities in The Bow high-rise (Calgary, Alberta, 2008-2012): regions of influence of plants.

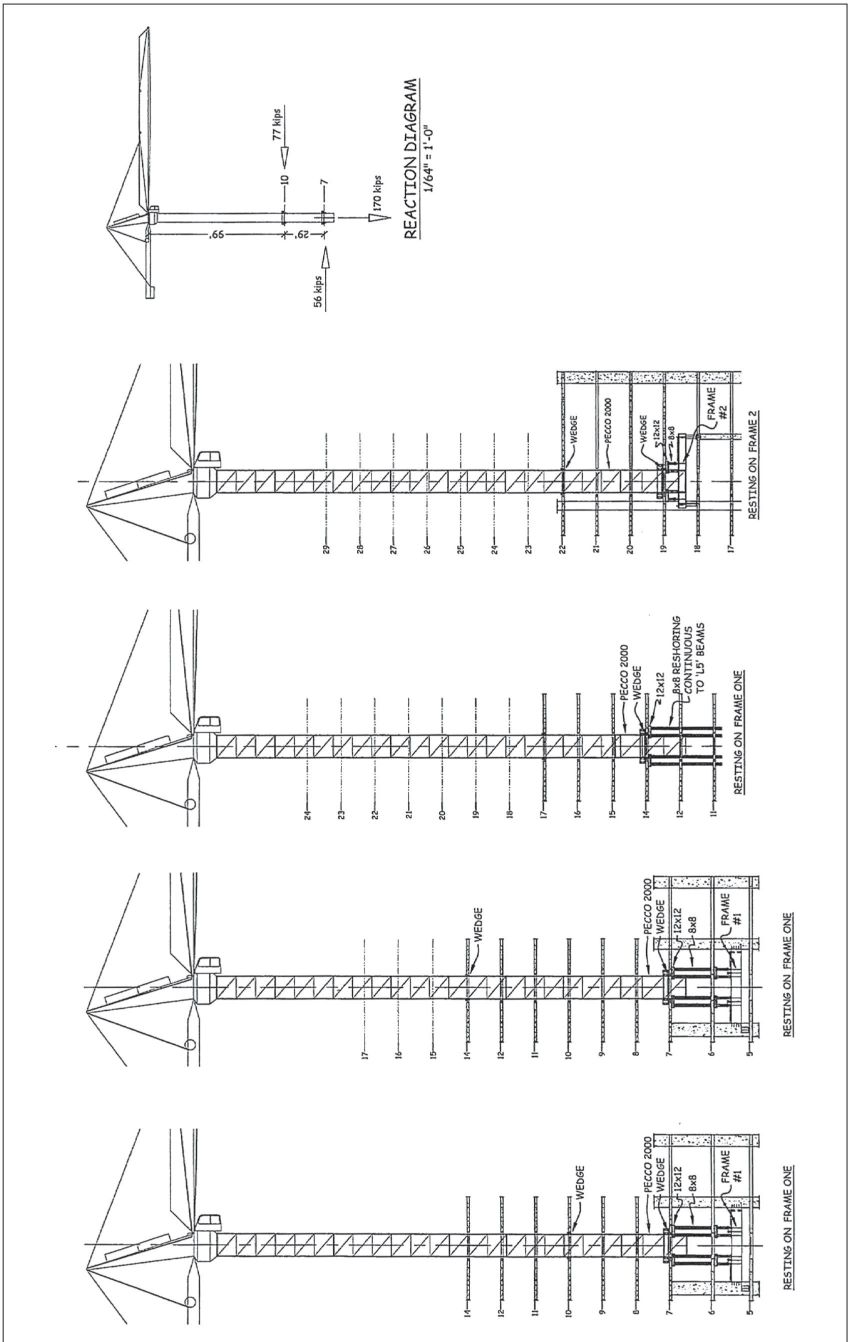

Figure 7. Innovative solution with climbing crane adopted for the construction of the Shangri-La Hotel skyscraper (Vancouver, British Columbia, 2006-2008).

Figure 8. Ice Tower B Edmonton, Canada.

be supported at two levels along the strong vertical elements of the central concrete core and the main columns of the building (Fig. 7). By proceeding in this way, the number of floors required to move the crane was reduced, with great advantages in terms of time and costs. In the field of tall buildings using an internal climbing crane, this idea was judged original by expert designers and builders and has since been used several times by NewWay in different variants.

For the sake of completeness, among the examples of innovative and original engineering solutions proposed or adopted on our sites, I would like to mention a couple more. The first is the A-FRAME system: this is a construction method for moving the crane more easily to higher altitudes using a metal structure set in contrast to the vertical resistant structures. The second is the TABLA system. This is a self-supporting formwork solution that involves the use of steel modules that are easy to assemble and simple to install for scaffolding/formwork on large concrete castings, especially for lofts.

To close this section, I would like to mention a number of tall buildings that have been built by NewWay, or are in an advanced stage of construction, and in which technological solutions have been employed on site similar to those described above. The Park

Place skyscraper, built in San Diego, is considered by visitors almost a symbol of the city, so much so that it is called "The Cathedral", for its design that vaguely resembles religious architecture. Other large buildings currently under construction and scheduled to open include the Ice Tower B (Fig. 8), which is part of the ICE District in Edmonton, Canada, and the Google Campus, which recently received the award for Best Green Project from ENR Engineering News Record in 2019.

4. Innovation and Tradition. As I move towards the conclusion of this lecture, I would like to touch on the issue of the term "tradition" mentioned in the title. For me, "tradition" means treasuring past experience, the skills acquired first at school, then at technical college for the building trade, and, gradually, in my now numerous real-life experiences on large building construction sites. "Tradition" also means globally proclaiming the Friuli banner, the experience of our ancient labourers, masons and master builders, and certainly also the unforgettable Friuli Model that allowed the region to rise again after hitting rock bottom in the tragic 1976 earthquake. But, if you'll allow me, there is more. "Tradition" for me also means respect for work and the worker. And in NewWay Construction the work, and especially the working relationships, are inspired by basic ethical principles. Among these, I like to mention:

- the motivating spirit of belonging to the company, that includes role-respecting teamwork but also the enhancement of individuals;
- the collaboration with employees, workers, technicians and managers, bearing in mind the real difficulties they encounter in transfers and on site, which at times are made more difficult by environmental and climatic conditions and the need to work at high altitudes. No employee is considered a mere implementer, but rather a participant in the project and the company's mission;
- respect for regulations and technical codes, but also respect for local customs and traditions. Obviously, this applies not only to the activities carried out in Canada, but in every country where NewWay operates;
- rewards extended to all employees who, through their willingness, availability and work, offer certainty and prospects for the company's future;
- the strict adherence to safety regulations in order to avoid any dangerous actions, so protecting employees and workers in the work environment;
- the ties of loyalty with customers and suppliers, indispensable for the continuous improvement of the company over time.

During my years of work I have learned that you must always improve and give your best in everything you do. In the field, I have learned new skills to better manage the staff and work teams working on the site. I believe that the future is made of ideas. New problems can always arise in the execution of projects, and a good manager must face them head on, seeking to solve them in the best way possible and, if necessary, introducing technological innovation to facilitate the solution.

The fusion of innovation and tradition in the construction of tall buildings does not represent a challenge to those who created the World, to great heights, or the desire for invincibility. It seeks to be a conscious push in the search for man's way forward. Looking up, when a job is finished, we see the sky, sun, moon, clouds and stars. It is then that we realise that we are tiny beings on a journey, wishing to leave an imprint of hope and joy.

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