PF2302 – Construction Technology

Report on Automatic Climbing Formwork

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Project Background

Project Topic: Doka Automatic Climbing Formwork

Project Aim: To revolutionize the trade of formwork in the construction industry using Doka ACF

Project Objectives

1. To explore this relatively new formwork concept/technology apart from the traditional erection of formwork in tall buildings.
2. To study and analyse the benefits of this formwork concept/technology

Project Methodology

1. Interview with Doka Formwork Pte Ltd (Singapore)
    - To get first hand detailed information from DOKA Formwork to gain better insights of their products
    - To share with us personal experiences with relevance to climbing formwork
2. Site visit to Ocean Financial Centre
    - To personally experience the site conditions of an actual on-going construction project that employs Doka ACF
3. Local and overseas case studies
    - To understand the successful application of Doka ACF in a variety of significant projects
    - To aid in the analysis of the benefits of ACF
4. Model making and video of the automatic climbing formwork
    - To enhance our illustration on how ACP works during presentation

1. Introduction

Concrete works is an indispensable process of construction, which determines the strength and stability of the structure. Cement, reinforcement and formwork come hand-in-hand. Without the use of formwork, the concreting work can never be carried out. Formwork is the "soul" of the concrete, and act as the mould of the concrete which in turn will affect how the buildings will turn out to be. The concreting process usually takes up a high percentage of the total time given for the whole construction project. Conventional formwork systems are found to be lacking in the efficiency and capability to fulfill the increasingly demands of today's architectural; aiming for taller buildings, and more complex buildings' shape.

In Singapore, jump form has been the most popular and widely used among various types of formwork. Doka's technical director, Mr. Michael Eder has pointed out that the formwork industry is revolving, new technologies will have a positive impact on the performance of formwork, and new formwork systems such as automatic climbing systems will slowly gain a higher popularity in the construction industry.

This report aims to explore an alternative for formwork in the industry, automatic climbing formwork, which is more efficient for construction of tall buildings. Its operations, specification, advantages and limitations, cost benefits, and safety measures will be further elaborated throughout the report. In addition, comparison between automatic climbing formwork and normal formwork are highlighted. Case studies will also be included for further illustration of the use of automatic climbing formwork in modern construction projects.

To achieve this goal, site visits and interviews were carried out with the assistance of Doka Formwork Pte Ltd, focusing on the SKE 50 plus automatic climbing formwork.

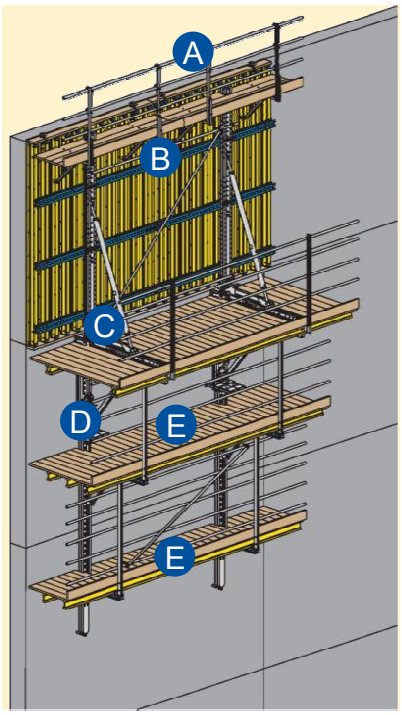
2. Specifications of automatic climbing formwork SKE 50 Plus

2.1 Key figures of SKE 50 Plus

Operate	Hydraulically
Loading capacity	50kN
Pouring height	2,7 m - 5,5 m
Max. wind speed during climbing	72 km/h
Climbing speed	5 min/m
Inclination	Approx. 15 degrees
Wall system	Large-area formwork Top 50 Framed formwork

Table 2.1 – Key figures of SKE 50 Plus

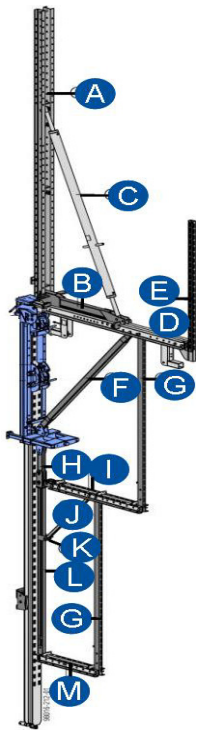
2.2 Components of SKE 50 Plus platform system



A Pouring platform
B Wall formwork
C Working platform
D Climbing profile
E Suspension platform

Figure 2.1 – Platform system

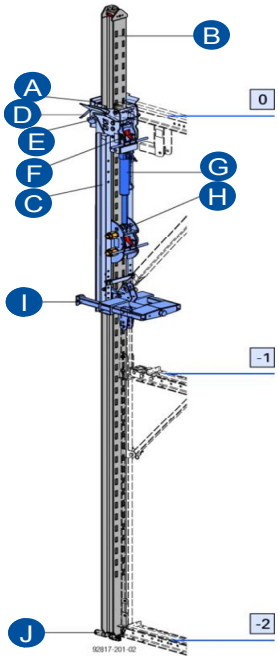
2.3 Components of SKE 50 Plus platform system (Detailed)



A Vertical wailing MF 3,00m or 4,00m
B Travelling gear SK 0,95m
C Plumbing spindle MF 3,00m or 4,50m
D Horizontal profile SKE 50 plus 2,70m
E Handrail post SK 2,00m
F Pressure strut SK 2,37m
G Suspension profile SKE 50 plus back
H Suspension profile SKE 50 plus jointed
I Multi-purpose wailing WS10 Top50 1,50m
J Strut SKE 50 plus 112cm
K Strut connection SKE 50 plus
L Suspension profile SKE 50 plus front 2,93m
M Multi-purpose wailing WS10 Top50 1,00m

Figure 2.2 – Detailed platform system

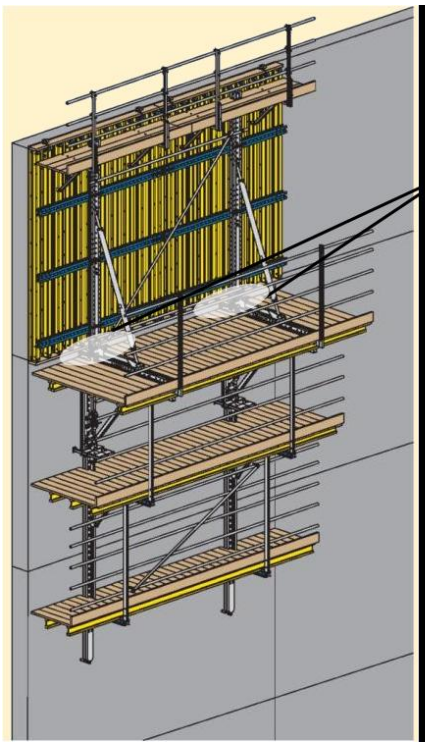
2.4 Components of SKE 50 Plus climbing system (Detailed)



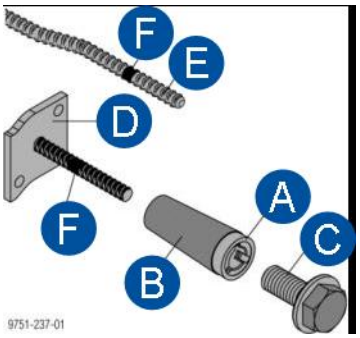
A Suspension shoe SKE 50 plus
B Climbing profile 450 SKE 50 plus
C Vertical profile SKE 50 plus
D Safety pin SKE 50 plus
E Suspension pin SKE 50 plus
F Lifting mechanism SKE 50 plus top
G Hydraulic cylinder 24 SKE 50 plus
H Lifting mechanism SKE 50 plus bottom
I Supporting carriage SKE 50 plus
J Supporting shoe SKE 50 plus

Figure 2.3 – Detailed climbing system

2.5 Components that help anchor SKE 50 Plus to building



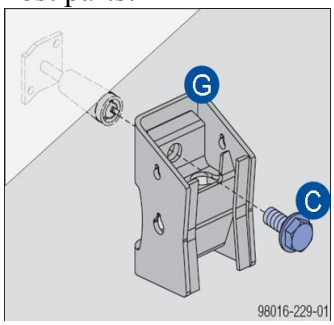
Component:





Suspension point:

Lost parts!



A Universal climbing cone 15,0 /20,0

B Sealing sleeve K 15,0/20,0

C Cone screw B 7 cm

D Stop anchor 15,0/20,0

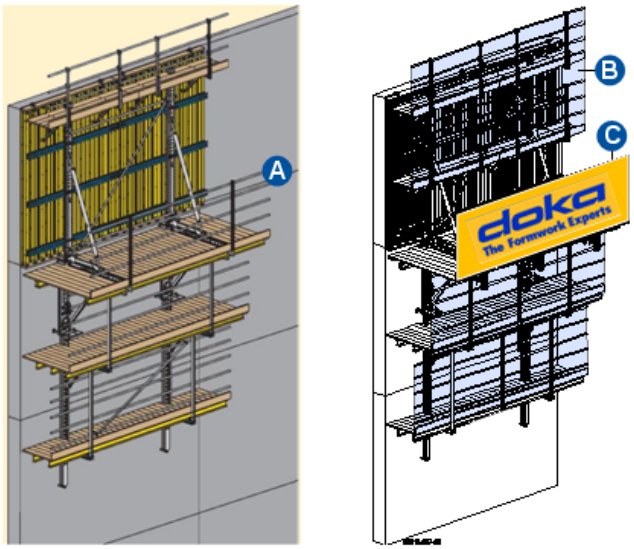
E Pigtail anchor 15,0/20,0

F Mark (Screw in length)

G Suspension shoe SKE 50 plus

Figure 2.4 – Components for anchorage to wall

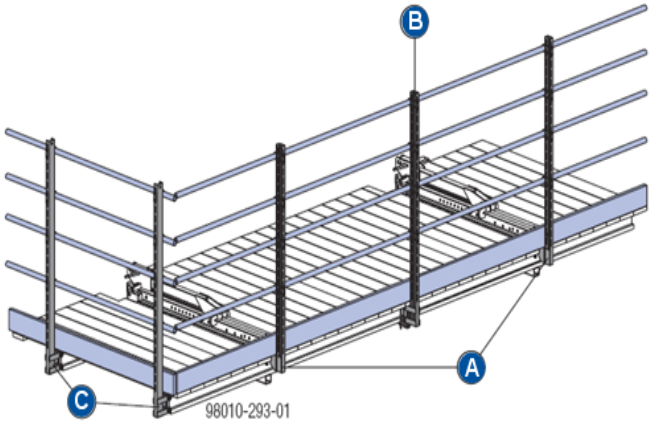
2.6 Components of SKE 50 Plus railing system



A Scaffold tube / planks
B Net housing
C Full housing

Figure 2.5 – Railing system

2.7 Components of SKE 50 Plus railing system (Detailed)



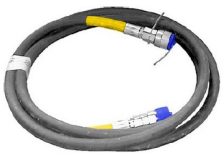
A Railings at the horizontal profile
B Intermediate railings
C Railings on the face side

Figure 2.6 – Railing system (Detailed)

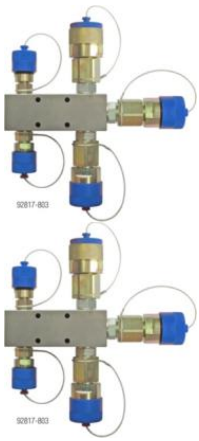
2.8 Hydraulic components of SKE 50 Plus



Hydraulic unit



Hydraulic hose SKE 6,50m



Line distributor S, & M



Hydraulic cylinder



Pipe clamp

Figure 2.7 – Hydraulic components

2.9 Component for lifting operation of SKE 50 Plus



Figure 2.8 – Remote control for lifting of SKE 50 Plus

2.10 Component for access to different platform levels of SKE 50 Plus



Figure 2.9 Integrated ladders for access

3. How SKE 50 Plus works?

3.1 Introduction automatic climbing formwork SKE 50 Plus

SKE 50 Plus is a revolutionary automatic climbing formwork system offered from Doka. The whole system is designed to be modular and can be assembled quickly. This is especially important in confined site. SKE 50 Plus climbing system is highly flexible and it provides optimum accommodation to geometrically complex building shape and can be used for structures of any height.

This versatile system uses hydraulic jacks to "jump" thus enables it to be crane independent. Even in high wind speed conditions, work can still be carried up safely. During operation, the wide working platforms and climbing brackets are always anchored in the concrete and it leads maximum safety for the construction crew. SKE 50 Plus is an efficient solution for any type of structure.

3.2 Operating procedures

SKE 50 Plus relies on hydraulic system to work. The sequence on how the automatic climbing formwork works vary between two stages, namely the start-up phase and the typical climbing stage. More details will be revealed in the following paragraphs.

3.2.1 Start-up phase

In this phase, the first segment of the concrete is being casted. During this stage, there are some necessary steps to be undertaken before the automatic climbing formwork can be jumped using hydraulic jacks. Basically SKE 50 Plus makes use of the previously casted concrete as an anchor of support and the crane to lift the platforms into place before it can climb by itself. The sequence is being explained below.

Pouring 1st casting section

1. Set up one side of the formwork
2. Determine and assemble the positioning-points
3. Position the reinforcement (refer to Figure 3.1)
4. Close and secure the formwork
5. Pour concrete into the first section

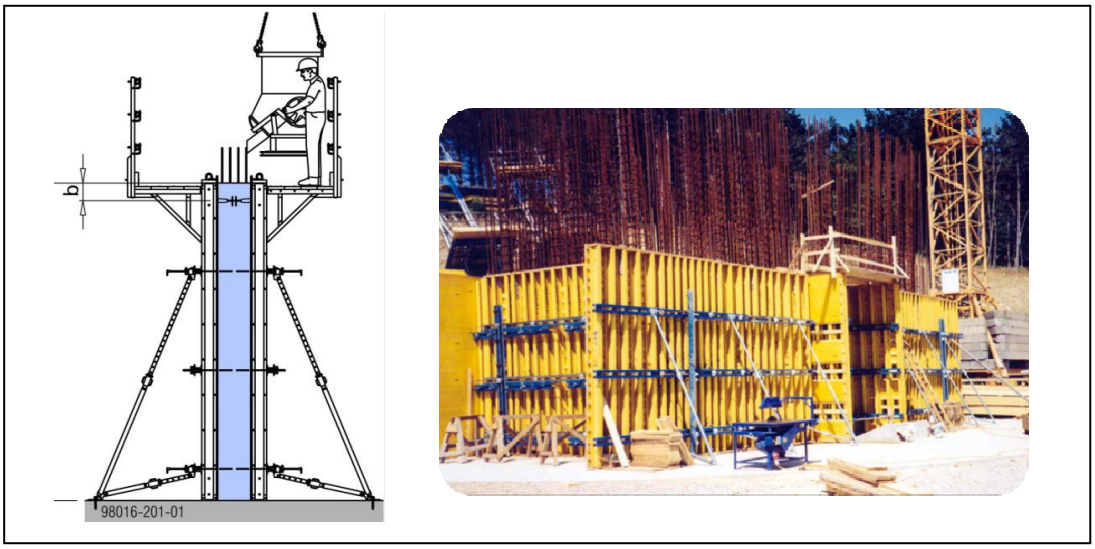


Figure 3.1 Reinforcement placed in position to pour the 1st section

Pouring 2nd casting section

1. Mount the suspension shoes with cones 25cm below top edge of 1st casted concrete section (refer to Figure 3.2 (a))
2. Attach the climbing scaffold into place on the suspension shoes with cones
3. Place the formwork on the climbing scaffold
4. Fix the positioning-points
5. Position the reinforcement (refer to Figure 3.2 (b))
6. Close the formwork
7. Pour concrete into this section (refer to Figure 3.2 (c))

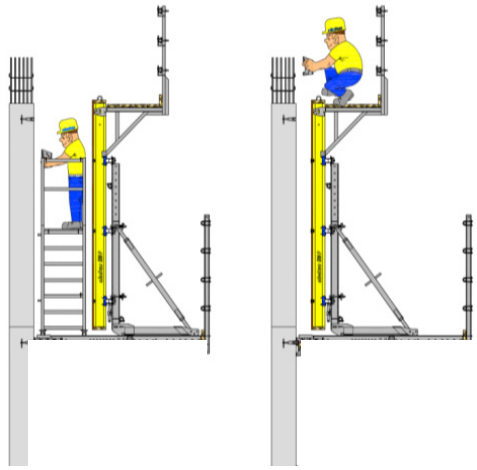


Figure 3.2(a) Cone and shoe assembly

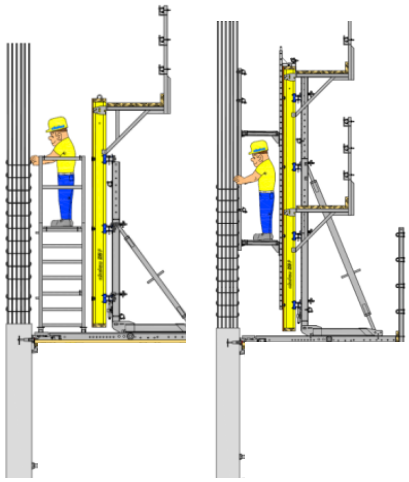


Figure 3.2(b) Fixing reinforcement



Figure 3.2(c) Setting up the formwork to pour the 2nd section

3.2.2 First hydraulic climb

1. Remove the formwork (Refer to Figure 3.3 (b))
2. Clean the formwork (Refer to Figure 3.3 (b))
3. Fix the top suspension shoe with cone (Refer to Figure 3.3 (c))
4. Lift the climbing profile by crane and attach it in place (Refer to Figure 3.3 (d))
5. "Climb" the entire Climbing scaffold and formwork using hydraulic jacks (Refer to Figure 3.3 (e) to 3.3 (l))

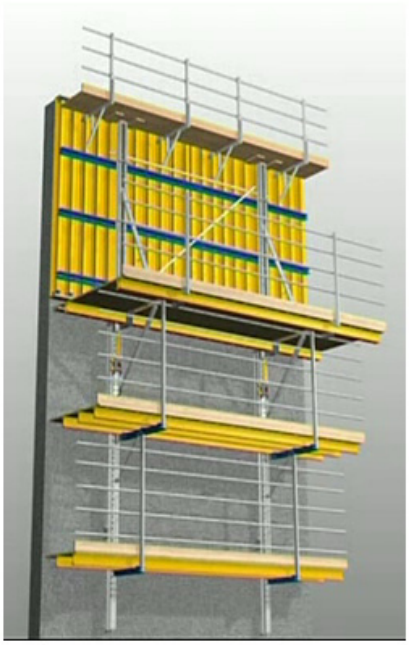


Figure 3.3(a) – Formwork in place after casting the 2nd section

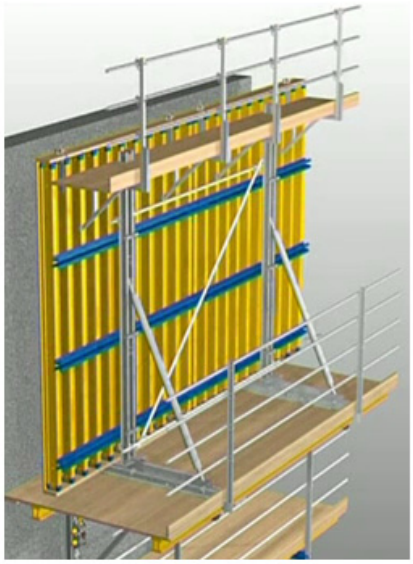


Figure 3.3(b) Remove the formwork and clean it



Figure 3.3(c) – Fix the top suspension shoes with cone at the 2nd casted slab (The main vertical profile of the Climbing bracket must be parallel to the concrete wall to ensure the verticality)



Figure 3.3(d) – Climbing profile fixed in position with hydraulic jack

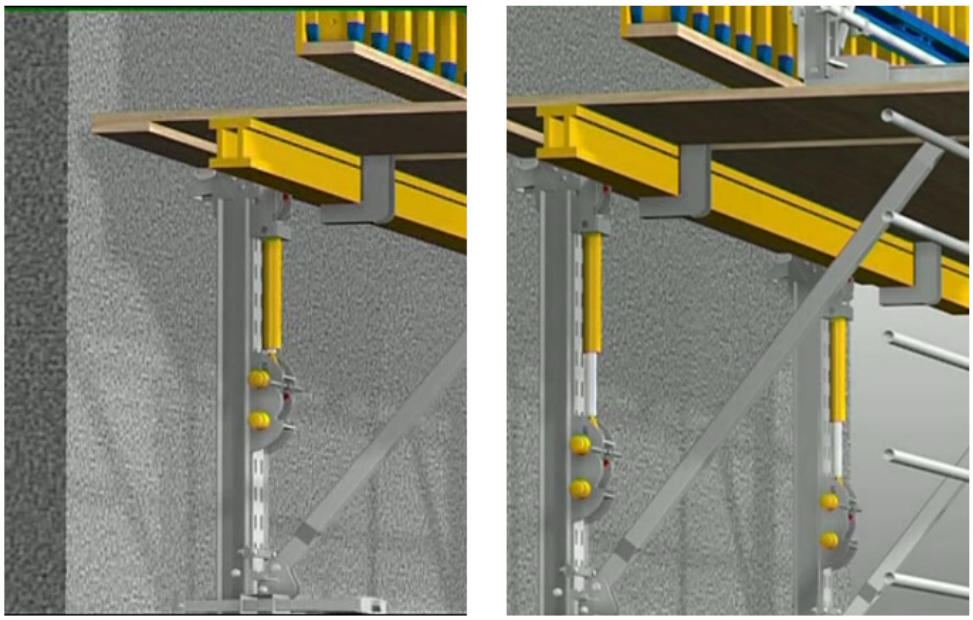


Figure 3.3(e) – Hydraulically "climb" by having the jack to retract and expand until the profile reaches the shoes at the top.

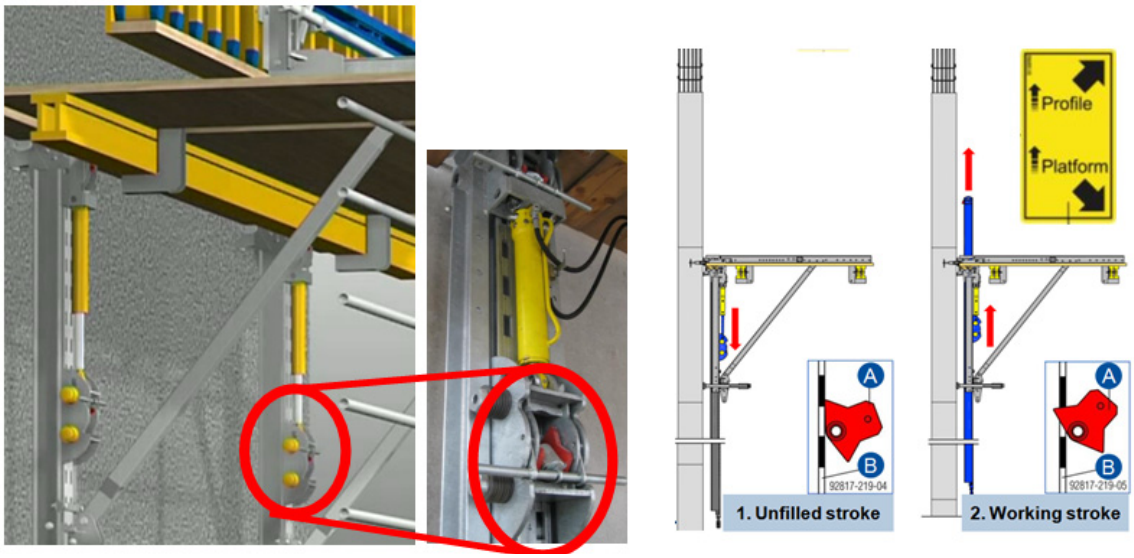


Figure 3.3(f) When climbing profile is being jacked up, the pawl (A) will be in the "unfilled stroke" position, allowing up-movement of the profile during the jack-up, and then shifted back to the "working stroke" position. These steps repeat until the profile reaches the suspension shoe at the top.

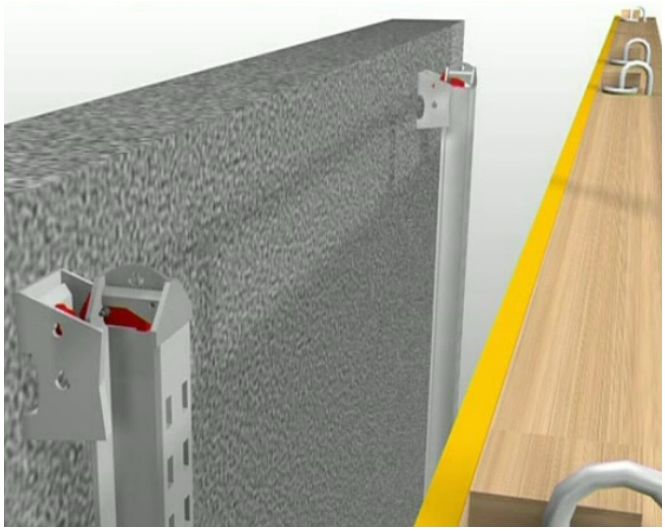


Figure 3.3(g) The Climbing profile reaches the shoes at the top

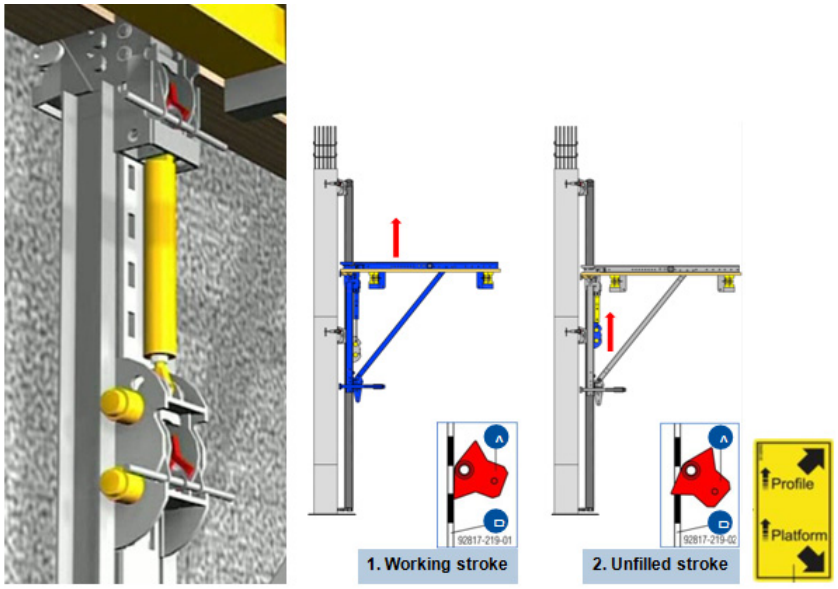


Figure 3.3(h) – When the Climbing profile reaches the suspension shoes at the top, the scaffold and formwork is ready to be lifted. The pawl (A) is now in the "working stroke" position allowing up-movement of the scaffold and formwork during the jack-up, and then shifted back to the "unfilled stroke" position. These steps repeat until the scaffold and formwork reaches the suspension shoe at the top.

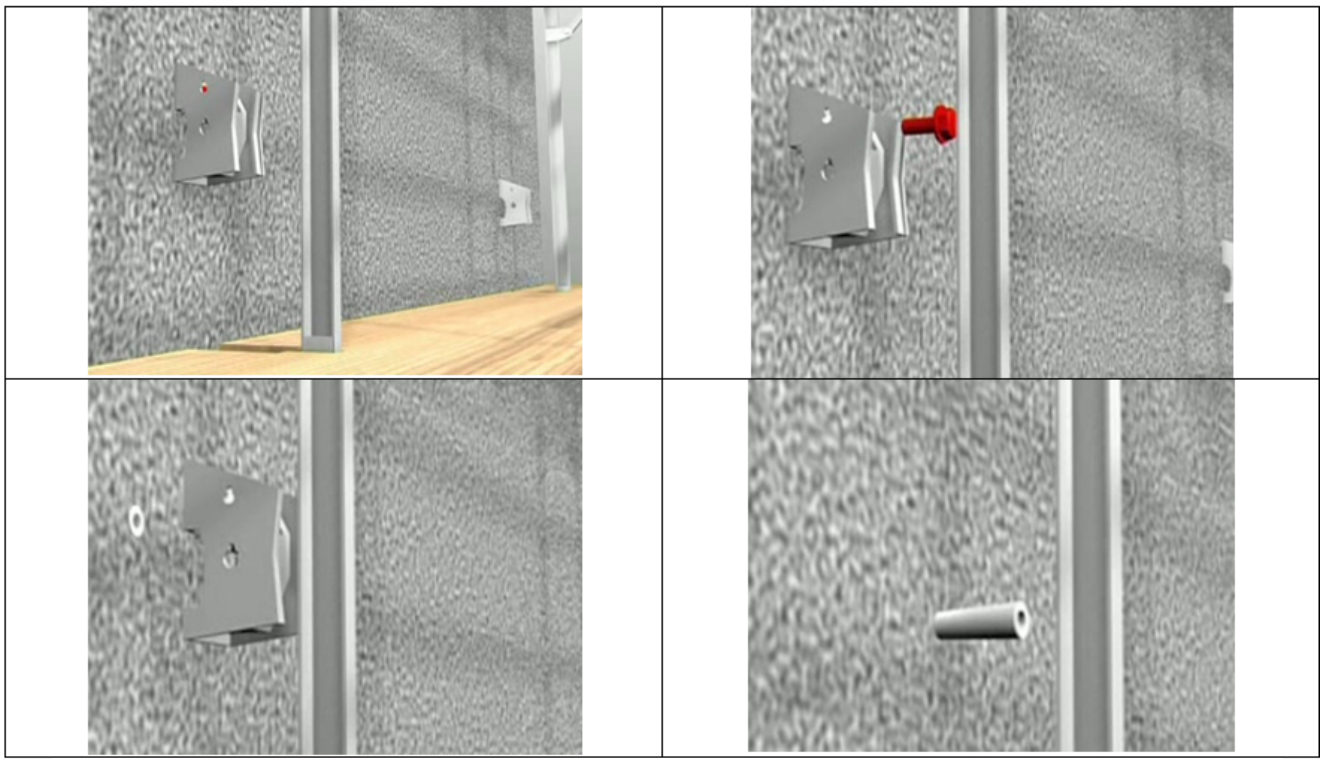


Figure 3.3(i) – Suspended shoes and cone previously mounted are ready to be removed before the climbing of the scaffold and formwork.

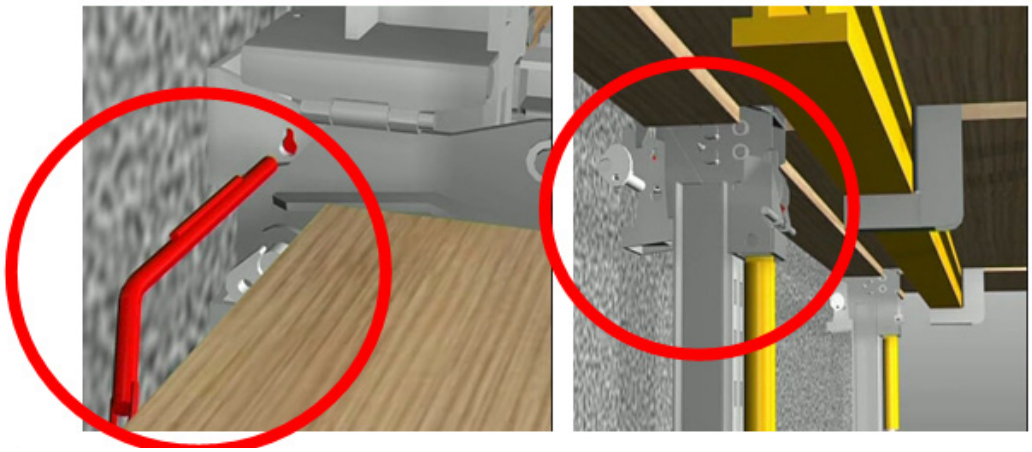


Figure 3.3(j) – The safety pin (on the left) and suspension pin (on the right) which support the scaffold and formwork are being removed to allow the system to climb.

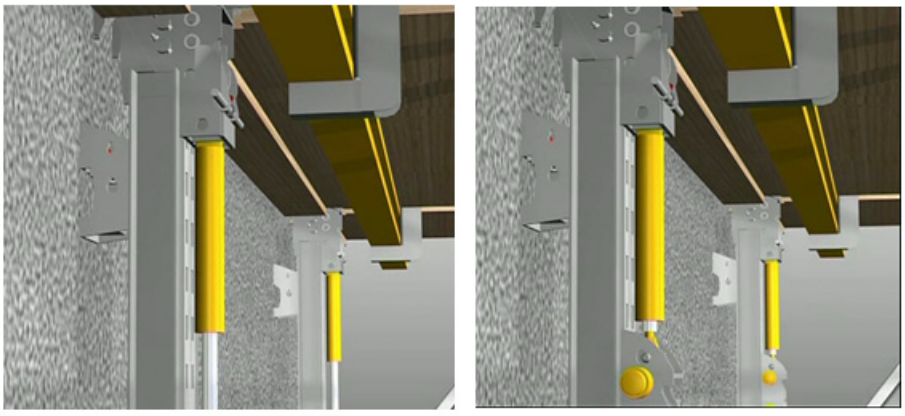


Figure 3.3(k) – The scaffold and formwork is being jacked up thereafter.

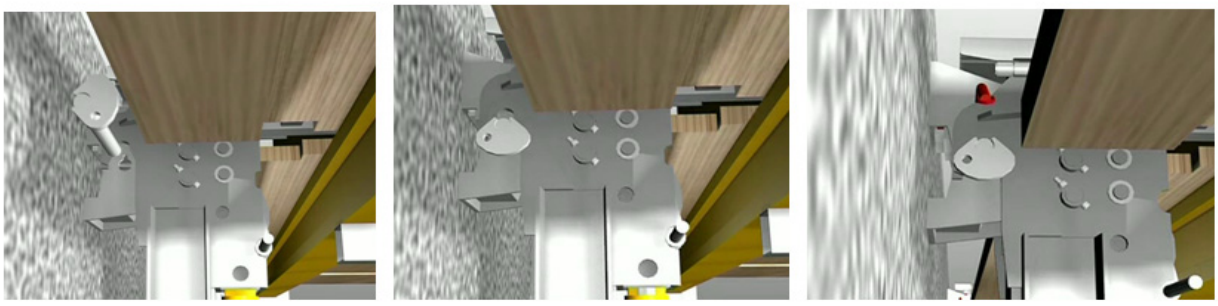


Figure 3.3(l) – The suspension pin and safety pin are used to secure the system to the shoes

3.2.3 Pouring 3rd casting section

1. Attach the suspended platform with the help of crane ((Refer to Figure 3.4)
2. Set up one side of the formwork
3. Mount the positioning-points
4. Place the reinforcement
5. Close the formwork
6. Pour this section

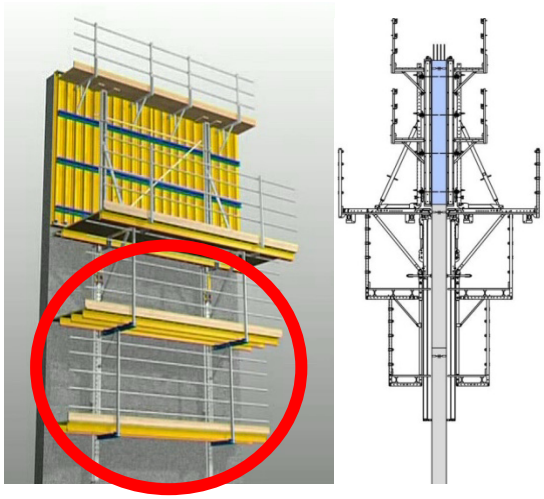


Figure 3.4 – Assemble the suspended platform with the help of crane.

3.2.4 Typical operating phase

During this phase, the system is able to climb by itself using the hydraulic jacks. Hence the following steps will be carried out so that the system can move on to the next level.

Climbing	**Pouring**
1. Strip the formwork	1. Set up one side of the formwork
2. Clean the formwork and the platforms	2. Mount the positioning-points
3. Mount the top suspension shoe with cone	3. Place the reinforcement
4. Hydraulically "climb" the climbing profile	4. Close the formwork
5. Dismount the bottom suspension shoe and cone	5. Pour this section
6. Hydraulically "climb" the entire Climbing scaffold and formwork	

Table 2.1 – Typical operating phase for climbing and pouring of concrete

3.2.5 Dismantling

The shoes and cones are removed and the whole formwork system is being lifted by crane and brought to the ground for dismantling. The time required is approximately 2/3 of its assembling time.

4. Comparison of Jumpform and Automatic Climbing Formwork

The main difference between jumpform and ACF lies in the usage of crane. Jumpform requires the usage of crane for every lifting cycle while ACF does not.

To better appreciate the advantages of automatic climbing formwork, a simple comparison between ACF and jumpform is presented in the table below.

	Jumpform	Automatic climbing formwork
Flexibility of formwork	Little	Improved: - height adaptability of suspended platform - formwork is retractable 1m for operating comfort - Adjustable width, enclosed on all sides
Loading capacity	Vary among different types	50kN
Pre-assembly	Low level	High level: wall formwork, working and suspension platforms
Lifting operation	Requires coordination between the crane operator and workers at the point of installation	Little coordination is needed with remote control
Lifting capacity	Restricted to one unit lifted at once by a crane	Many platform units can be lifted at the same time: commonly 20 units
Weather conditions	Positioning by crane is restricted by wind speed	Unaffected by wind speed of up to 72km/h since it is anchored to the structure in every situation

Table 4.1 – Comparison between jumpform and ACF

5. Benefits of Doka Automatic Climbing Formwork

Extrapolating from the comparison of the fundamental features of jumpform and ACF, the benefits of ACF is further examined in this section.

5.1 Leverage on the expertise of Doka

Being a full-line supplier in all areas of cast-in-situ building construction, Doka offers a package of services that is tailor-made for customers' needs in addition to the comprehensive line of formwork products. In other words, the formwork can be customized to accommodate inclinations, widely varying shapes, and height. The added value for customers will be maximized by adapting the formwork solutions to the customer's requirements in a situation-specific way whenever the standard formwork is unable to meet customers' requirements. The experienced engineering department will then plan and design for any desired shape. The use of the formwork systems is being ensured to be the optimum by the field service technicians in the implementation phase. The Doka "Ready-to-Use" service will pre-assemble custom formworks as needed for customers' special requirements. This pre-assembly eliminates the need to assemble formwork on site, thus saving space.

For example, in the case of Burj Dubai, the formwork is customized to resist lateral and seismic forces. However, with customization, it will be less economical as the formwork cannot be reused.

In addition, the following benefits of using Doka's expertise are stated in their website[1]:

- Optimised formwork engineering based on technical and time requirements of the construction project
- Site-oriented planning and engineering expertise, including customised solutions
- Computer-aided first-use planning and equipment requirements calculation

5.2 Flexibility

As mentioned in the preceding section, the Doka ACF is usable for different forms, shapes and height. Specifically, the Doka ACF can be used for inclinations up to +/- 15^{o} and this is

[1] http://www.doka.com/doka/en_global/services/formwork/planning/index.php

more advantageous for internal inclination due to the difficulty in positioning the formworks if cranes were to be used.

This has been proven by the usage of Doka ACF in two construction sites located in Dubai: the world's tallest building, Burj Dubai as well as the slanted building, Capital Gate Tower. The latter has an inclination of 18^{o} and this shows that the formwork has yet met its potential, in terms of its inclination capability.

5.3 Independence of Crane

As ACF is independent of cranes, it can be used especially for structures with unique architecture/special locations. At times, structures are built on sites which are difficult for cranes to reach. For instance, bridge works are difficult for cranes to access especially when they reach the middle of the bridge. Hence, ACF is the solution to structures located in difficult sites, such that it is difficult to provide crane access. This can be seen in Devil's Slide Bridge, California, where ACF-SKE 50 was used to build the bridge.

In certain projects that are located in confined sites, space constraints have made it difficult for tower cranes access. This is especially so when the neighbouring buildings are near to each other, such as Singapore's Central Business District area. Furthermore, space constraints limit the number of tower cranes that can be deployed on-site. With limited tower cranes, it would be beneficial to reduce its utilization load by using ACF. As a result, better allocation of the usage of cranes for other hoisting purposes that solely rely on crane can be achieved.

Hence, the ACF would be the perfect solution to such projects as it greatly reduces the dependency of tower cranes.

5.4 Cost efficiency

5.4.1 Manpower

As compared to jumpforms, Doka's ACF is designed in such a way that it requires lesser manpower for operation. In the case of jumpforms, manpower is needed to operate the crane for hoisting and to position the jumpform accurately. Whereas for ACF, manpower can be reduced since the lifting of ACF is achieved hydraulically during its "climbing" phase. By reducing the manpower through the use of ACF, the direct cost of hiring them would be reduced or the manpower originally needed for jumpform operations could be deployed for other work processes.

5.4.2 Equipment

In addition, if ACF were to be used to reduce manpower needed, the dependency of crane for core wall construction is also greatly reduced. As the daily cost of crane usage can be very significant, reducing its need for core wall construction and allocating it for other work processes that can solely depend on crane will capitalize on the money spent on crane usage.

5.4.3 Time

Through the usage of ACF, the process of each cycle of core wall construction is made simpler since the steps involved are relatively lesser than jumpforms. To elaborate, the ACF would be able to lift 20 units simultaneously unlike jumpform where only one formwork can be lifted at a time. In jumpform operations, hoisting and positioning of the formwork is needed for each formwork unit. Thus, this could be a more complex and time-consuming process than using ACF whereby all formwork units are lifted simultaneously.

Therefore, with a simpler process, the overall cycle time is shortened and shorter time implies lesser indirect cost. In addition, incentives may be given if the project is completed earlier. These cost benefits in relation to time will be illustrated in the succeeding section.

5.4.4 Cost analysis in relation to time

In every construction work process, the cost component consists of fixed costs and variable costs. For the construction of core wall, the fixed costs mainly consist of materials such as concrete, reinforcement bars and formwork. These fixed costs remain the same regardless of the period of construction. Variable costs on the other hand vary accordingly to the construction duration. These variable costs include labour, equipment cost and project operations overheads needed to support the construction process.

To illustrate the cost savings of using SKE 50 Plus formwork, Figure 5.1 shows the cost breakdown of a generic construction project. A ballpark estimate is that the cost of structural construction makes up 33-percent of the total construction cost. According to

Mr. T.G. Lim, sales director of Doka Formwork Pte Ltd (Singapore), the rough estimate of fixed and variable cost would be 65-percent and 35-percent respectively.

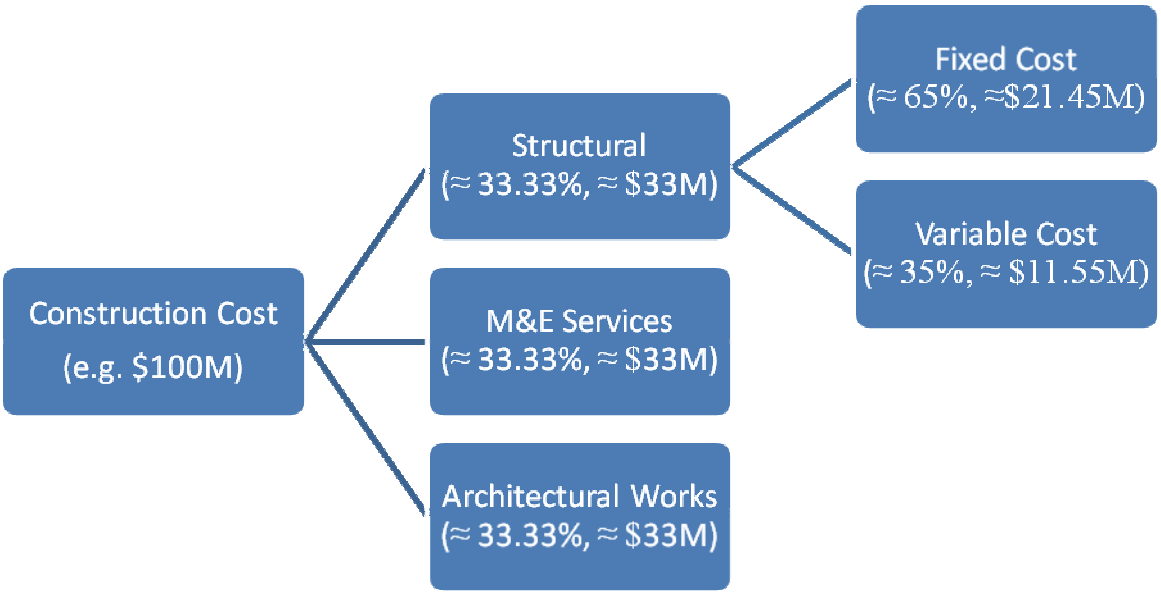


Figure 5.1 – Cost breakdown of a generic construction project

Looking at this generic construction project, the variable cost of the construction of structural component is $11.55 million. If the construction period of the structural component is one year, the variable cost per day would be:

$$\frac{\$11.55M}{365\ days} \approx \frac{\$32{,}000}{\text{day}}$$

Hence, if we can reduce the time taken to construct the core wall, we could save a significant amount of money in terms of variable cost.

In addition, construction of the structural component generally lies on the critical path of the schedule. In particular, the construction of floor slab is dependent on core wall construction. Following that, the work process of M&E services and finishes (such as internal wall, ceiling) can only start after the floor slab has been built.

In sum, a lot of activities are dependent on the core wall construction. By reducing the construction time of core wall which is on the critical path, the total duration could be shortened. Incentives and bonuses might also be handed out by the developer/owner if the building commission date is brought forward.

5.4.5 Price performance ratio

A good automatic climbing formwork is essential for the sustainability of daily construction progress, acquiring workplace safety, and the quality of the concrete results. If looked simply, using a normal jumpform can result in a more cost-effective construction project. However, one must look at the return on investment in terms of total cost savings, performance and quality. Hence, as much as ensuring money is wisely spent, it is also crucial to adhere to an ideal price/performance ratio to obtain optimal deliverance of the performance of the formwork during construction for its price.

5.4.6 An edge over Doka's closest competitors

The Doka automatic climbing formwork is capable of lifting up to 20 units with a single hydraulic lift – a stark difference as compared to its closest competitors. This feat is made possible by the powerful hydraulic unit. Being able to provide such a capability would mean a significant time and cost savings.

A larger lifting capability would reduce the time taken to lift the climbing brackets. Taking for example a generic project that requires 20 units to construct a core wall, the lifting cycle would be just one if the Doka ACF were used (*see* Figure 5.25.2, top). On the hand, it could take two to three lifting cycles to lift the same number of climbing brackets using competitors' system (*see* Figure 5.22, bottom). In addition to the increase of time needed for more cycles to lift all the 20 units, relocating and fixing of the hydraulic units for each lifting cycle would also increase the time.

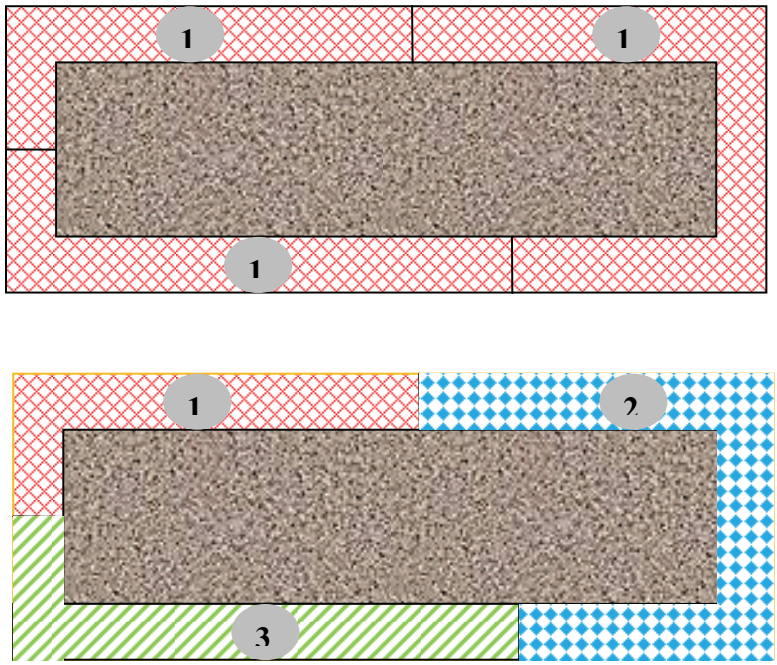


Figure 5.2 – Lifting cycles of Doka ACF (top) and competitors' (bottom).
***number in circle denotes number of lifting cycle(s).**

Although it could be argued that in the competitors' systems, more hydraulic units could be deployed to achieve a single lifting cycle, there could be cost implications as a result. Rental, purchase, storage and maintenance of more hydraulic units would add on to the cost.

Using only one hydraulic unit would also mean more maneuvering space for workers on the platform. If the platforms are cramped with hydraulic units, there could be higher risks of safety compromises. This brief comparison with its competitors' systems has shown that Doka ACF has advantages not just in cost and time, but also safety.

6. Safety with Doka

6.1 Safety concerns in the construction industry

In the construction industry, accident could be the last thing industry players would like to have. According to Chew (2009), "accidents may result in high direct and indirect costs". Some of these implications are highlighted in the table below.

Direct	Indirect
• Medical costs • Workers' compensation and other insurance benefits	• Negative publicity to the corporations involved • Reduced productivity • Job schedule delays • Damage to equipment and facilities • Low morale among workers • Possible additional liability claims

Table 6.1 – Direct and indirect costs of accidents (adopted from Chew, 2009)

In addition to the implications that are listed in Table 6.1, there are also fines imposed by the law. With the introduction of the Workplace Safety and Health Act (WSHA) in 2008, heftier penalties are meted out to individuals and corporations when found in breach of the Act. The punishments for individuals could be up to $200,000 fine and/or 24 months' imprisonment, and for corporations, up to $500,000 fine. This hefty fine could be enough to wipe out a company's profit-margin for the project or even cause the company to run into liquidity problem which may subsequently cause it to wind-up.

The enforcement framework of WSHA provides for the issuance of Remedial Orders (ROs) if the accident or safety breach is a mild one, or in serious cases (e.g. when fatality occurs), Stop Work Orders (SWO). Time has to be spent to comply with the RO; and when there is SWO, work could not be carried out until the order has been lifted. As a result of these orders, job schedules would be delayed.

As the saying goes: "one live lost is one too many", one should do his best to minimise the occurrence of accidents in the workplace, for life is precious. However, the current state of safety in the construction industry is relatively perturbing as seen in the following section.

6.2 Current state of safety in construction industry

According to the Ministry of Manpower (2008a), accidents reported in the construction industry was 2,864. This figure is the highest among the various industries and it accounts for nearly 26% of the total reported workplace accidents in Singapore. Of these accidents, "fall from heights" and "struck by falling objects" were the two main contributing factors (MOM, 2008b).

Latest statistics (MOM and WSHC, 2009) have shown that these trends have also been observed in the first half of 2009, where the construction industry "continued to have the highest number of workplace fatalities" and also "have overtaken manufacturing as the highest contributor" for permanent disablement. "Fall from heights" (30%) and "struck by falling objects" (22%) were again the main contributing factors for fatalities. In addition, crane lifting operations account for more than half of the "struck by falling objects" cases.

Although it is not known how many of these accidents (if any) were attributed by the operations of formwork construction, it is good to look at how the various safety features of the Doka SKE 50 automatic climbing formwork can help to minimise these major accidents that could have resulted from formwork operations.

6.3 Safety features of Doka's ACF

In this section, Doka's SKE 50 will be used to illustrate the safety features of Doka's automatic climbing formwork. This is due to the fact that most of the safety features between all Doka's automatic climbing formwork are similar, thus we will just look into one of the available automatic climbing formworks that is present in Doka.

The following features ensure maximum safety throughout the concreting phases of core wall construction.

6.3.1 Climbing scaffolds are anchored to the concrete at all times

When a newly casted concrete wall is formed, the climbing cones (shown in Figure 6.1), having a large load capacity of 15 kN each, are always embedded into the concrete wall. The whole climbing formwork will then rest on these climbing cones. Therefore, this allows the climbing formwork to be sturdily anchored to the concrete at all times by the climbing cones as it climbs higher to the next phase of concreting.

Each climbing formworks are secured by 4 climbing cones tightly, as such, the climbing formwork will not be affected by the lateral loads such as wind as it proceeds to climb higher.

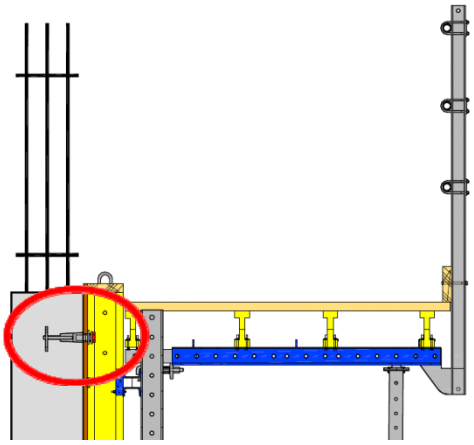


Figure 6.1 – A cone (load capacity of 15kN) being embedded in a cured concrete wall

6.3.2 Hydro-mechanical lifting of the formwork platforms, with no need for crane

The whole formwork system is automatically self-climbed, powered using hydraulic unit and hydraulic cylinders. As such, this eliminates the use of crane to lift the formworks. As lifting by crane poses a danger of falling formwork, this danger will be prevented with the use of automated self climbing system. In addition, application of the automatic climbing formwork allows workers to stand on the platform safely even when the formwork is in the process of climbing. On the contrary, in the case of jumpforms, when the crane is hoisting the formwork to the next level, workers are not allowed to stand on the platform of the jumpform due to safety reasons. In fact, it is stated in the WSHA (Construction) Regulations 2007 that riding on any load while it is being hoisted is strictly prohibited.

6.3.3 Wide working platforms and width of walking ways

As seen from Figure 6.2, the widths of the platforms at each part of the formwork are of comfortable distance which is more than 1 metre in width. This allows ample space for the workers to maneuver around the platform as they carry out the tasks without restrictions. The widths of the corner walk ways are of distance 0.50 metres, 0.80 metres and 1.00 metres at the different level of platforms in a single formwork (*see* Figure 6.3). The widths are wide enough for the workers to travel from one profile to another with ease.

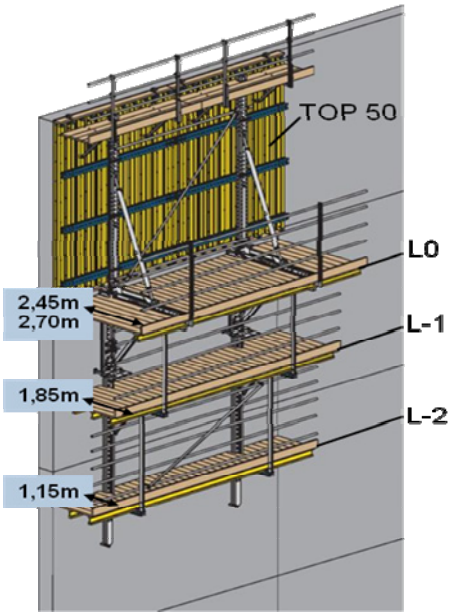


Figure 6.3 – Width of platforms

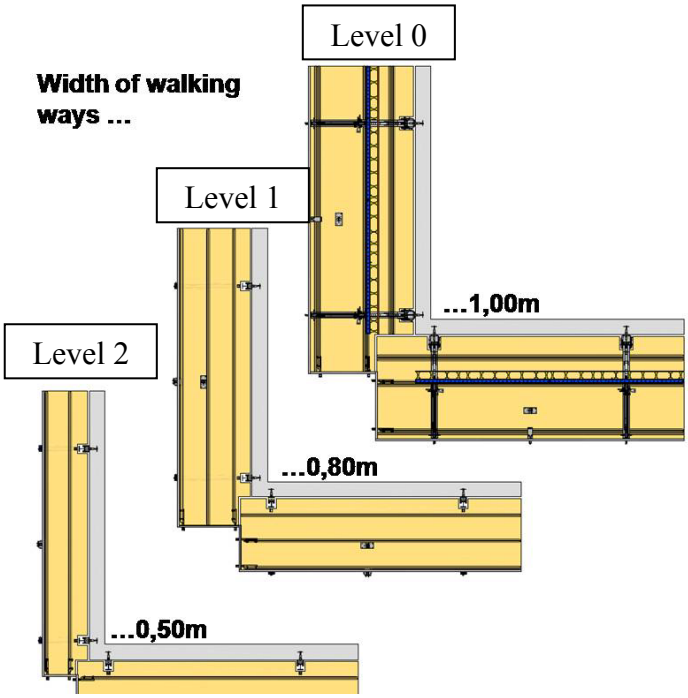


Figure 6.2 – Width of corner walk ways

6.3.4 Wider working area between wall and formwork

The formwork is retractable to an approximate distance of 1 metre (*see* Figure 6.4). This gives the workers more operating comfort to carry out the placing of reinforcement cage, washing of the formwork or removal of the climbing shoes.

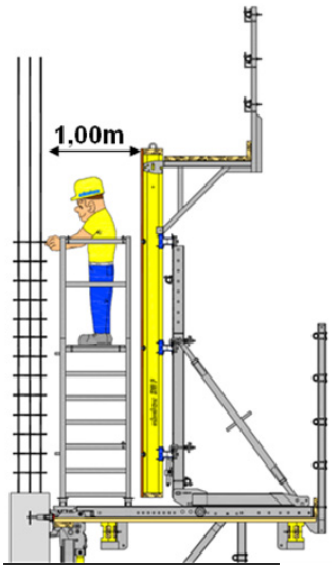


Figure 6.4 – A distance of 1 metre between the wall and formwork

6.3.5 Handrail post

The height of handrail post is of 2 metres in height which maximizes safety to prevent any workers from falling off the formwork at great heights (*see* Figure 6.6).

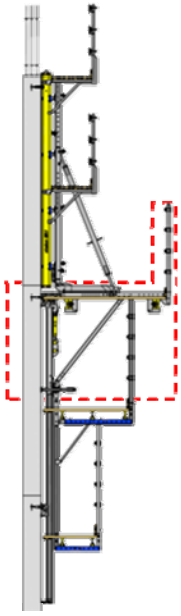


Figure 6.5 – Working platform with handrail

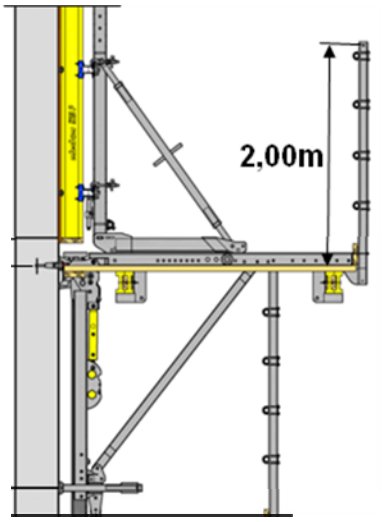


Figure 6.6 – Tall handrail post of 2 metre

6.3.6 Protection Housings

Different protection housings are available, which can be fixed onto the formwork for maximum protection of the workers as well as preventing any falling debris. Protection housings can come in 3 forms, namely scaffolding tubes/planks, net housing and, full housings as seen in Figure 6.7. Different housings are employed based on the degree of protection needed. As the construction of the building climbs higher, a stronger housing such as full housing will be recommended to ensure greater safety.

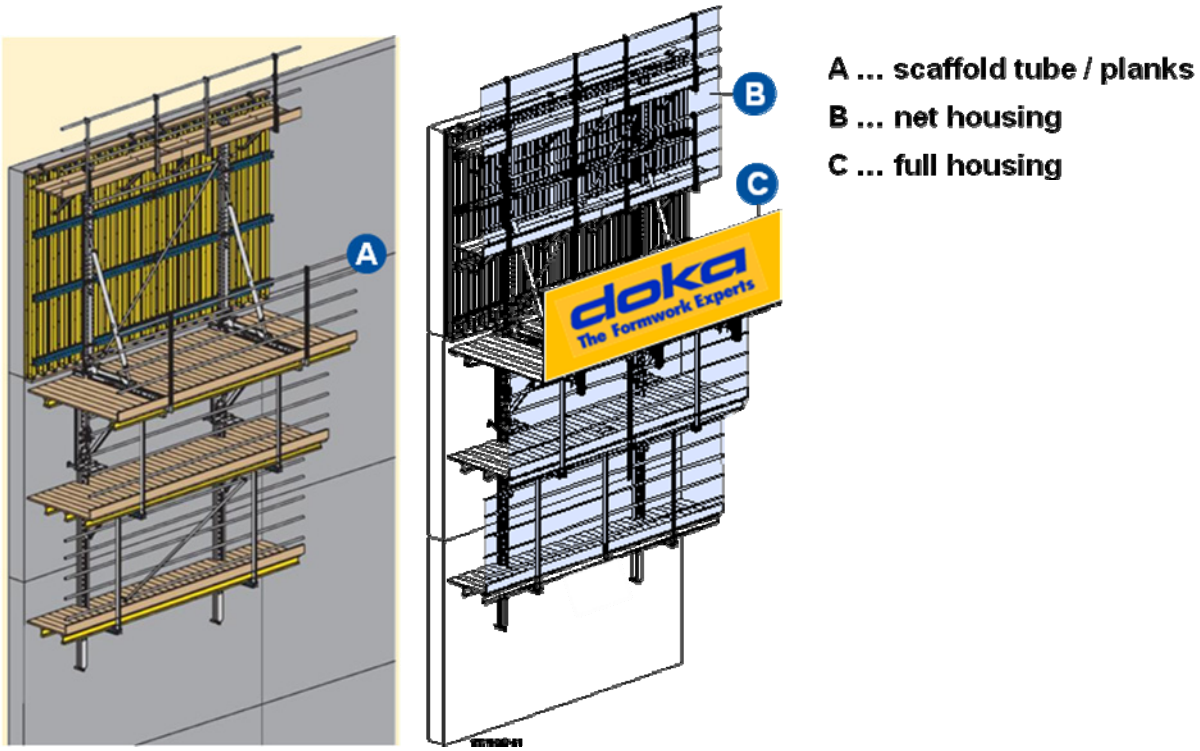


Figure 6.7 – The three types of protective housing in Doka ACF

6.3.7 Independence from weather conditions

Crane lifting has to cease to operate if bad weather conditions were to occur. However, as the ACF is independent from the use of crane, work can still proceed under such conditions.

In addition, work can still carry on safely under high wind as it climbs higher, unaffected by wind speeds of up to 72 kilometres per hour. During rain, the formwork can still continue to climb safely unlike the jumpform where the erection of the formwork has to be stopped due to danger factor during raining periods. Moreover, more formworks can be lifted up with the use of the hydraulic jets compared to the use of crane where its lifting capacity is lower.

7. Possible factors to why is Automatic climbing formwork not widely used in Singapore?

7.1 High initial cost

As compared to jumpform that is commonly used in Singapore, ACF has higher initial cost due its technology and the numerous accessories that are involved in the operation, such as the hydraulic jacks.

7.2 Height restriction to build tall buildings in Singapore

Due to land limitation in Singapore, buildings are generally close to one another. As such, tight security is needed to prevent intrusion of privacy. This is especially true when buildings are near political buildings or the airport. For example, Plaza Singapura was built with only 6 storeys tall, with 4 basements storeys. This is due to the height restriction as it is in close proximity with The Istana. The Istana is a very sensitive building; therefore, a number of restrictions are posed to its surrounding buildings due to security issues.

7.3 Construction projects are mainly not so complicated

Singapore's architectural designs are generally more simplistic and small scale. Therefore, most of the construction deploys normal formwork – Jumpform, due to the fact that it is extensive enough to cater to such construction.

8. Case Studies

Recently, there have been many large projects around the world that use automatic climbing system for their core wall construction. Some of the prominent projects are Burj Dubai and Capital Gate Tower in Abu Dhabi, which will be further explored in this section. In addition, automatic climbing system has also received attention in the local construction industry. An example of a local construction project will be Ocean Financial Centre, which is still under construction.

8.1 Ocean Financial Centre



At the heart of the Singapore's Central Business District (CBD), a new distinctive building is emerging, the Ocean Financial Centre (OFC).

OFC is designed by the world-renowned architectural firm, Pelli Clarke Pelli, which marks its presence in the architectural of various landmark commercial developments in major financial cities such as the World Financial Centre in Beijing, Two International Finance Centre in Hong Kong, the Mori Tower at Atago Green Hills in Tokyo and Petronas Towers in Kuala Lumpur.

Formerly, there were only three buildings sharing the title of tallest building in Singapore, namely United Overseas Bank Plaza One, Republic Plaza and Overseas Union Bank Centre, which are all located in the CBD area. Now, joining the league is a 43-storey skyscraper-

Ocean Financial Centre, which serves chiefly as a home to financial corporations. This development will be an outstanding addition to the skyline of Singapore



8.1.1 Project Background

Project background	
Project type	Office Building
Location	Raffles Place, Singapore
Commencement date	April, 2009
Construction duration	approx. 2 years
Year of completion	2011
Building Data	
Total Height of Structure	240 m
Number of storey	43 storey
Forming systems	Automatic Climbing Formwork; Xclimb60 for core wall

8.1.2 Observations from the Site visit to Ocean Financial Centre

8.1.2.1 Construction duration

The construction duration allowed for OFC redevelopment is of a short duration of approximately two years. In a busy district like CBD, it is preferable that construction projects do not take too long to complete due to issues such as traffic control, construction affecting the other adjacent buildings in operation by its noise and etc. This is especially so when OFC is considerably a tall building whereby the time to construct will be relatively longer.

In addition, overhead cost in CBD area is expensive due to its prime location. Hence, it is vital to shorten the duration so as to maximize the profit and minimize the cost.

8.1.2.2 Confined site

During the site visit, it is observed that the construction site for Ocean Financial Centre is considerably confined. Surrounding the perimeter of the construction site, there are adjacent office buildings at close proximity (refer to Figure 8.1.1 and 8.1.2) such as the Ocean Tower, of which, was directly right beside the construction of OFC (as seen in Figure 8.1.1). Adding on to the problem of having a constrain site with adjacent building; the Ocean Towers are actually still remaining its operation while OFC is being redeveloped.

As a result, it is not reasonably feasible to have too many cranes on site, to prevent the operation of crane affecting the adjacent building, as well as the construction itself. The radius of the boom is restricted especially when existing building is just beside. It is observed that there are only two tower cranes within the building itself and they are utilized for the whole massive and relatively huge construction. Thus, the use of cranes should be efficient and productive, so as to not delay the entire project. However, the construction site could have arranged for mobile cranes for some lifting operation occasionally, but was not being seen during the site visit.



Figure 8.1.1 Adjacent building at Close proximity such as Ocean Tower



Figure 8.1.2 Adjacent buildings at the surrounding of construction site (Star indicating the location of OFC construction)

8.1.3 Solution to fulfill the construction requirements

To fulfill the requirements of the OFC construction project, Doka's Xclimb 60 automatic climbing formwork is being chosen for its in-situ concrete core wall construction. With the aid of Xclimb 60 automatic climbing formwork, the core wall of the 240m tall OFC structure is being "climbed" within a relatively short span of time- five-day cycle.

In addition, in view of the limited number of cranes on site due to its confined site as mentioned earlier on, Xclimb 60 automatic climbing formwork is able to "climb" by itself, which eliminates the use of crane. As such, the crane can be used for other tasks, which decreases the opportunity cost for the use of cranes. With the use of Xclimb 60 automatic climbing formwork and tower crane concurrently, productivity rate will increase and duration of construction can also be shortened.

The use of Xclimb 60 automatic climbing formwork also decrease the probability of accidents happening as Xclimb 60 automatic climbing formwork is attached securely to the building during operation.

Where safety is of concern in the workplace during the slab-forming operations, the top four storey levels are enclosed by the self-climbing Xclimb 60 protection screen as seen in Figure 8.1.4, to prevent the falling of debris and the like.

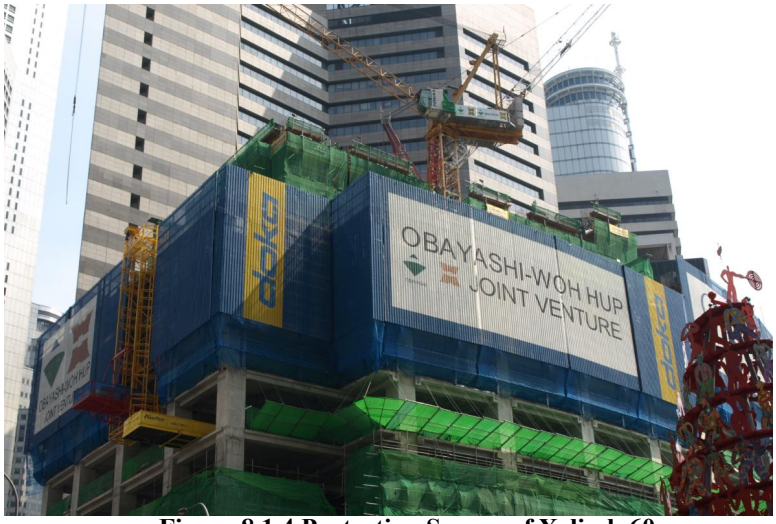


Figure 8.1.4 Protection Screen of Xclimb 60

Xclimb 60 automatic climbing formwork advances the construction duration, in such a way that it is able to complete the task at a short time span (core wall is being "climbed" in a five-day cycle), hence increasing the speed of construction. It allows the use of the limited number of cranes for other activities instead of waiting for the tedious formwork processes to be completed, so that other activities can start/proceed on, hence decreasing the opportunity cost of crane. Xclimb 60 automatic climbing formwork also decreases the probability of having accidents on site with the use of cranes, in which preventing the hassles created if an accident happens unfortunately such as project delay, inspections, and etc, and increase the project duration.

Cost is always of a paramount importance and of priority in construction projects; hence, these considerations are important especially when working in the CBD area. There are some costs that are distinctive in the CBD area, one of which is the transportation cost and another, the opportunity cost of land usage. These two costs will be discussed in the next two paragraphs.

In the CBD area, an obstruction to the traffic is undesirable as it could impact greatly on the country's economy. To prevent any obstructions, there is need for careful planning and

restricted transportation hours of materials and equipments to sites in the CBD area. As a result, the cost of transportation could be higher than other area.

Next, in a premium district such as the CBD area where land prices are high, it would make absolute business sense for any developer/owner to maximize their return on investment for their property. The construction phase at most time does not usually generate any income for the developers; it is only when the building is fully constructed will the value be increased since it can be occupied or rented out. For this reason, developers/owners would want to shorten the construction duration in order capitalize on the fact that they can maximize their profit sooner.

The use of Xclimb 60 automatic climbing formwork has eased the pressure on crane time to a great extends and kept work moving ahead promptly. Not forgetting that OFC has a relatively short construction duration, hence it is necessary to reduce the duration of the forming phase.

8.2 Capital Gate Tower



The United Arab Emirates, constantly shocking the world its new fascinating and creative buildings, is bringing today's architectural to a whole new horizon. Priming among them Dubai and Abu Dhabi, are constantly outdoing one another with record-breaking construction projects. Spectacular and breathtaking structures are mushrooming in the Arabian Gulf: the tallest building in the world- Burj Dubai, the innovative structure- Burj al-Arab, and now, the massively inclined building- Capital Gate Tower.

8.2.1 Project Background



Project background	
Project type	Executive 5-star hotel
Location	Abu Dhabi; Dubai
Construction duration	Quarter 3 2007 to Quarter 4 2009
Year of completion	End of 2009
Building Data	
Total Height of Structure	165 m
Number of storey	35 storey
Forming systems	Automatic Climbing Formwork; SKE 50 for core wall

8.2.2 Design of Capital Gate Tower

The Capital Gate Tower, slanted 18 degrees from the vertical. (Refer to Figure 8.2.1)

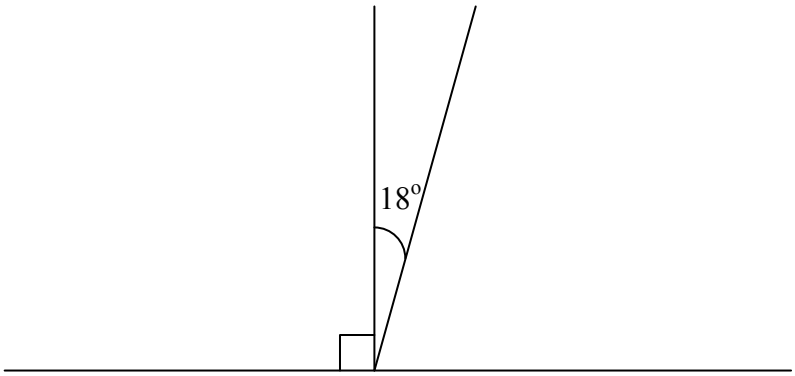


Figure 8.2.1 18° inclination from the vertical

Capital Gate Tower (Figure 8.2.2) is currently the most steeply inclined building in the world. In comparison, Capital Gate Tower is more than four times as slanted as the famed Pisa tower in Italy (Figure 8.2.3). Prior to restoration work at Pisa Tower between 1990 and 2001, it is leaning at 5.5°, now the tower is slanted at about 3.99°.



Figure 8.2.2 Capital Gate Tower



Figure 8.2.3 Pisa Tower

In consideration to the extreme inclination of the Capital Gate Tower, the central in-situ concrete core is characterized by an elliptical layout, and a large number of shafts, and is embedded into the massive reinforced concrete foundation This is designed in such a way to

transfer the horizontal loads leaving from the extreme inclination, and assure the tower against both wind loads and earthquakes.

8.2.3 Solution for the inclined Capital Gate Tower

With its uttermost inclination and height, this tower is pushing the limitations of what is technical practicability, hence necessitating the use of innovative construction technologies. To facilitate the construction of the building, the main contractor - Al Habtoor Engineering Enterprises Co. LLC. turns to Doka for the formwork solution of its central core wall (Figure 8.2.4). Considering the designing factors of Capital Gate Tower, Doka's automatic climbing formwork SKE 50 is selected to fulfill the requirements. The deciding factors of using Doka's automatic climbing formwork were the technically convincing formwork solution and the complete package of services aimed to optimise every phases of the concrete forming processes.



Figure 8.2.4 Doka's Automatic Climbing Formwork in Capital Gate Tower

In view of all the considerations of the project, 78 units of Doka automatic climbing formwork SKE 50 and more than 1300 m² of large-area formwork Top 50 are used to form the in-situ concrete core. As Doka is able to draw from experience from other projects such as Burj Dubai, the Top 50 formwork is altered and was reinforced with extra steel walings to withstand the increased hypostatic pressure exerted by the concrete, as result of the inclination of the shaft-walls. In addition, the corner zones of the Top 50 elements are accommodated with specially made steel walings and reinforced with steel form-facing.

In view of the extreme slant structure, the suspension shoes are customized so that SKE 50 can be safely guided up the structure core. Furthermore, Doka utilized thicker tie-rods to increase the load-bearing capacity of the SKE 50's climbing bracket and working platforms, all these help to ensure safety during all phases of operating the formwork systems.

With the aid of the high-performing SKE 50, the Al Habtoor site crew is able to form, reinforce and pour one casting section every week. The SKE 50 also allows a total of 42 casting sections to be carried out with no change of form-facing hence saving precious time and resources. In addition, the use of powerful SKE 50 is able to raise up to 30 climbing brackets at a time, hence expediting the construction process and improve productivity.

In order for the system to be quickly put into use, the platforms of the SKE 50 were pre-assembled and supplied to the site by Doka, which were then set up under the supervision of an experienced field service technician. With this, it also save up space for the elimination of on-site assembly.

8.2.4 Feedback from the client

"Doka has fulfilled the tough requirements for this formwork assignment to our complete satisfaction. In particular, it was the detailed planning of the forming operations, the comprehensive oversight provided during the shell construction phase and the high safety standard of the automatic climbing formwork that convinced us", emphasises Mohammad F. Zakaria, Acting Project Director, Abu Dubai National Exhibition Centre Phase 3 Capital Gate.

8.3 The Burj Dubai



The Burj Dubai that is completing in the last quarter of 2009 will be the tallest building in the world. It has been designed to be a mixed-development, consisting of hotels, residences and offices. This mega-scale development is part of the roadmap of Dubai's government in diversifying their economy from oil-based to service- and tourism-oriented. With such development, the city will be put on the world's map for this remarkable achievement, thus attaining its goals as it garners more international recognition and consequently more investments.



8.3.1 Project Background

Project background	
Project type	Hotel, residence, office tower
Location	Dubai, United Arab Emirates
Construction duration	40 months
Construction commencement	Feb 2005
Year of completion	End of 2009
Building Data	
Total Height of Structure	818 m
Number of storey	206 storey
Forming systems	Automatic Climbing Formwork; SKE 100 for corewall

8.3.2 Design of Burj Dubai

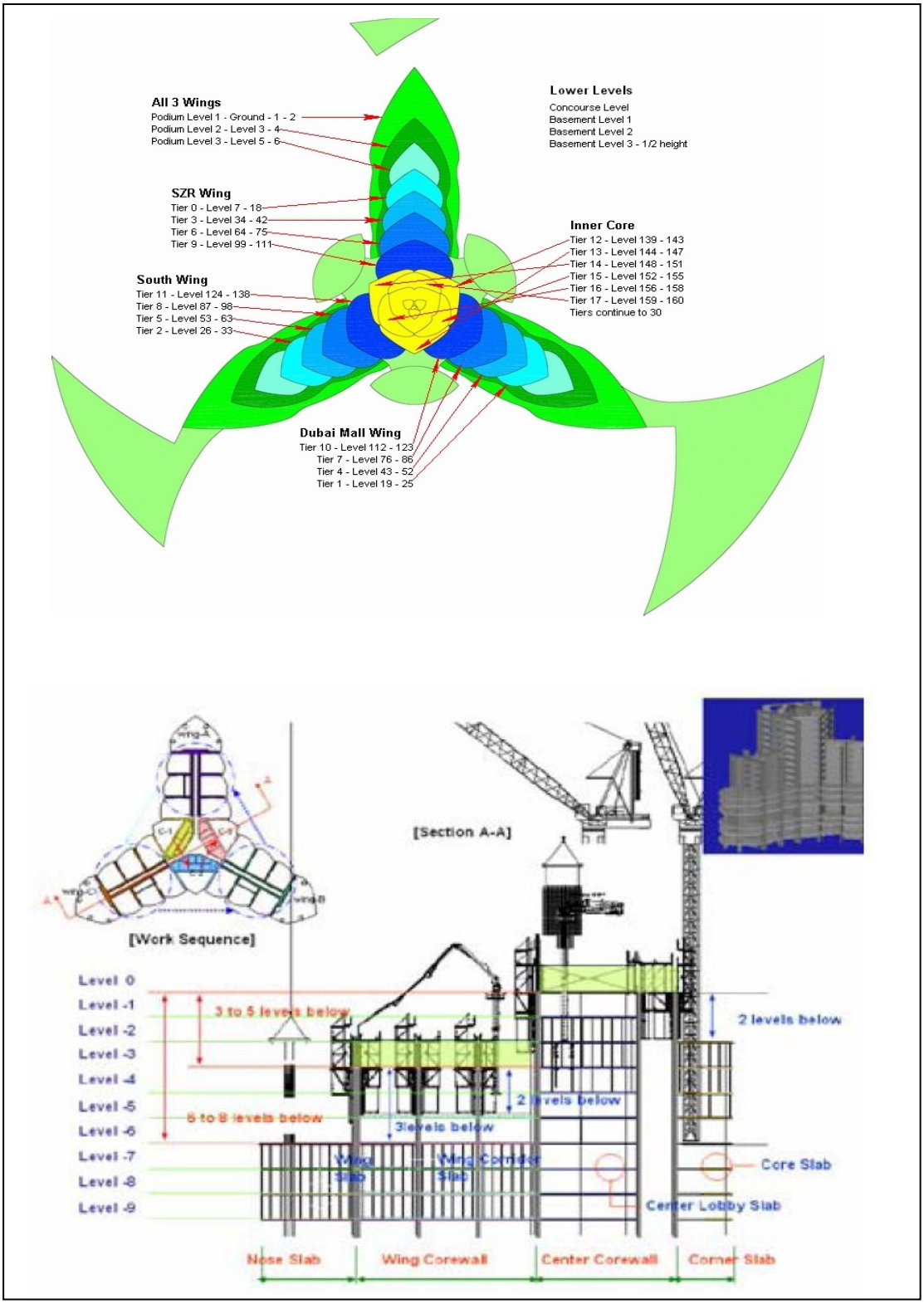


Figure 8.3.1 Y-shaped, wing-walled structure core design

The Burj Dubai, the world's tallest skyscraper, possesses a design that posed grave challenges to formwork-engineering and construction since the emergence of its construction plan in year 2005. Its Y-shaped, wing-walled structure core design as shown in Figure 8.3.1,

stipulates no less than 32 changes in layout as it tapers upwards. And this is where a magnificent formwork system has to be summoned in order to meet such exigent demand of the architectural design.

The Burj Dubai consists of one center corewall and three wing corewalls which require the extensive Doka's automatic climbing formwork (ACF), SKE 100, for their construction.

8.3.3 Tough requirements or challenges and their solutions for the Burj Dubai's construction

For this Burj Dubai's construction project, there are many tough requirements and challenges posed. As such, detailed formwork system and design are required to ensure all these requirements are met and all these challenges are overcome. And Doka's ACF has no doubt proven itself to be capable of doing so. The following content shall further elaborate its efficiency and capability.

8.3.3.1 Demanding architectural design

Upon understanding the preceding section, it is not hard to imagine how much difficulty the formwork experts has to experience in order to plan the formwork system for such demanding architectural design. For its Y-shaped, wing-walled structure core design that stipulates no less than 32 changes in layout as it tapers upwards, Doka had to plan all the way to the final detail for allowance that catered to each of these adaptations. Every time when the layout changed, separation points in the platform system would facilitate the formwork solution to be modified steadily and safely. Moreover, this is only accompanied by marginal impact upon the cycle time, hence explained the competency of Doka's ACF.

8.3.3.2 Meeting project schedule

Furthermore, Doka's highly efficient and easily-operated ACF has also enabled the storeys to be poured in a three-day cycle. Even Samsung's Project Director Kyung-Jun Kim had also commended Doka's ACF for its efficiency in allowing them to meet their schedule for the Burj Dubai's project, "As the in-situ concrete core was being built ahead of the floor-slabs, construction progress on the whole building was entirely dependent on the Doka's automatic climbing formwork solution. The Doka climbing formwork system functioned with machine-like precision, allowing us to complete the in-situ concrete core within the original timetable."

8.3.3.3 Extreme climatic conditions

Dubai's extreme climatic conditions were also another harsh factor that pose great challenge for the formwork experts in their formwork system planning and design. Due to the fact that the desert climate is directly next to the open sea, large temperature fluctuations between day and night are frequently experienced. Climatic conditions as such, regularly resulting in aggressive sandstorms with wind speeds of greater than 100 km/h. However, Doka's ACF was designed to handle wind speeds of up to 200 km/h thus overcoming the extreme challenge pose to both men and materials.

8.3.3.4 Safety concern

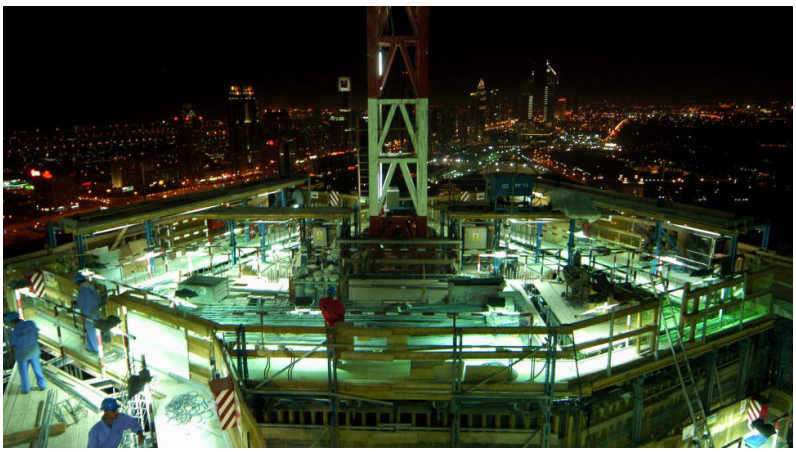


Figure 8.3.2 Partial snapshot of Doka's ACF fully enclosed working platforms for center corewall

Doka's fully enclosed working platforms for its ACF as shown in Figure 8.3.2 has helped the construction of the corewalls to achieve utmost workplace safety; even the exposed slab edges are also protected by its ACF protection-screen system during the floor-slab construction operations on the subsequent storeys. All these proficient safety features in-built in the ACF ensured that all operations progressed favorably and generally without accident.

9. Conclusion

In conclusion, automatic climbing formwork (ACF) has been applied overseas, creating different types of shapes and height of structures. This is attributable to its advantages of being highly flexible, being crane-independent, being cost efficient and having outstanding safety features; however, it is still not deployed widely in Singapore. This could be fundamentally due to three key reasons: high initial cost, height restriction to build tall buildings in Singapore and local construction projects being less complex.

Besides illustrating the advantages of using ACF and reasons why it is not widely adopted in local context, this report has also presented the details of the typical SKE 50 Plus, involving its specifications and its operation, as well as the comparison of Jumpform and ACF.

The cost benefit analysis in this report has also in fact demonstrated that in the long run, ACF is indeed worth investing in the first place due to its cost efficiency and optimal price-performance ratio. ACF will no doubt gain popularity among clients seeking value for money in the future.

10. References

- Burj Dubai reaches 601 m on schedule: World record using Doka Formwork Technology (n.d.). Retrieved 9 October, 2009, from http://www.doka.com/doka/en_global/whatsnew/news/pages/05187/index.php
- Burj Dubai: rising safely to a record height (n.d.). Retrieved 9 October, 2009, from http://www.doka.com/doka/en_global/services/presscorner/pages/04777/index.php
- Chew, Y.LM. (2009). *Construction Technology for Tall Buildings, 3rd Edition*. Singapore: World Scientific
- Doka - All About Concrete. (n.d.). Retrieved 8 October, 2009, from http://www.doka.com/doka/en_global/planning/concrete/pages/00198/index.php
- Doka - Products - Automatic Climbing Formwork SKE. (n.d.). Retrieved 9 October, 2009, from http://www.doka.com/doka/en_global/products/climbing/ske/index.php
- Doka - Ready-to-use service. (n.d.). Retrieved 12 October , 2009, from http://www.doka.com/doka/en_global/services/formwork/ready/index.php
- Doka - USA Training 2009. (n.d.). Retrieved 12 October , 2009, from DOKA: http://www.doka.com/imperia/md/content/dokausa/services/dokatraining/1.pdf
- Doka - What's New . (n.d.). Retrieved 12 October, 2009, from DOKA: http://www.doka.com/doka/en_global/whatsnew/news/pages/06242/index.php
- Doka (n.d.). World record for “Leaning Tower of Abu Dhabi”. Retrieved October 15, 2009 from http://www.doka.com/doka/en_global/whatsnew/news/pages/05998/index.php
- Hoe, Y.N. (22 February 2008). "*Construction crane topples over at NUS, killing 3 men*". Retrieved October 25, 2009, from http://www.channelnewsasia.com/stories/singaporelocalnews/view/330527/1/.html
- Leaning Tower of Pisa (n.d.), Retrieved October 25, 2009, from http://en.wikipedia.org/wiki/Leaning_Tower_of_Pisa
- Ministry of Manpower (MOM) (2008a). *Workplace Injuries by Industry and Degree of Disablement, 2008*. Retrieved October 15, 2009 from http://www.mom.gov.sg/publish/etc/medialib/mom_library/Workplace_Safety/wsh_statistic_2008.Par.7700.File.tmp/Workplace%20Injuries%20by%20Type%20of%20Accident%20and%20Industry,%202008.pdf

- Ministry of Manpower (MOM) (2008b). *Workplace Injuries by Type of Accident and Industry, 2008*. Retrieved October 15, 2009 from http://www.mom.gov.sg/publish/etc/medialib/mom_library/Workplace_Safety/wsh_statistic_2008.Par.7700.File.tmp/Workplace%20Injuries%20by%20Type%20of%20Accident%20and%20Industry,%202008.pdf
- Ministry of Manpower (MOM) and Workplace Safety and Health Council (WSHC). (2009). *MOM & WSHC Media Release on WSH Statistics Report Jan to Jun 2009.* Retrieved October 15, 2009 from http://app.wshc.gov.sg/cms/Portals/0/WSHC/NewsRoom/MOM_&_WSHC_Media_release_on_WSH_Statistics_Report_Jan_to_Jun_09_and_two-prong_approach_to_address_work_fatalities.pdf (Media Release) and http://app.wshc.gov.sg/cms/Portals/0/WSHC/NewsRoom/Annex-WSH_Statistics_report_Jan_to_Jun_2009.pdf (Statistics Report)
- Ocean Financial Centre (n.d.), Retrieved October 25, 2009, from http://www.keppelland.com.sg/com_sg_ob.asp
- Ocean Financial Centre Keppel Press Release (October 2007) , Retrieved October 18, 2009, from http://www.oceanfinancialcentre.com/news/latest-news.html
- Paradise in Italy: Tuscany (n.d.) Retrieved October 11, 2009, from http://www.paradiseinitaly.co.uk/index.php?page=tuscany
- Price / Performance Ratio. (n.d.). Retrieved 6 October, 2009, from http://en.wikipedia.org/wiki/Price-performance_ratio
- Special Report: Formwork. (n.d.). Retrieved 9 October, 2009, from http://www.constructionweekonline.com/article-5068-special-report-formwork/1/print/
- Tall Buildings of Singapore (n.d.), Retrieved October 25, 2009, from http://www.emporis.com/en/wm/ci/bu/sk/?id=100422
- This is what the most leaning building in the world looks like (2009), Retrieved October 12, 2009, from http://gizmodo.com/5272598/this-is-what-the-most-leaning-building-in-the-world-looks-like
- Wimmer, R. (2009). *Doka climbing formwork*, unpublished Microsoft Powerpoint Presentation, Doka Formwork Pte Ltd.

11. Legislations

Herein is a list of legislations that were referred to in this report:

- Workplace Safety and Health Act (Cap. 345A)
- Workplace Safety and Health (Construction) Regulations 2007